HOST-PARASITE RELATIONS AND MANAGEMENT OF *BELONOLAIMUS LONGICAUDATUS* ON POTATO AND COTTON

By

WILLIAM T. CROW

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1999

ACKNOWLEDGMENTS

I would like to thank my cochairs, Drs. D. W. Dickson and D. P. Weingartner, for allowing me to pursue my dream of earning the doctor of philosophy degree. They truly support graduate education and are willing to work hard to do so. I have learned a great deal from each of them, and I hope to have the same commitment to science exhibited by them.

I also would like to acknowledge the two men who have most influenced my life, and without whose example this work would never have been completed. My brother, Larry G. Crow, taught me never to give up and to live my own life without compromise. He taught me that it is all right to be different if you love what you do. My father, Max R. Crow, instilled in me a love for science at an early age. While never formally educated, he knew more about everything than anyone else I know.

My wife, Locell, and my daughters, Abigail and Joy deserve my deepest appreciation and thanks. Without their support and encouragement I would never have either undertaken nor completed this project. They have sacrificed greatly while their husband and father worked so hard, and still loved him.

The staff at the University of Florida Agricultural Research and Education Center at Hastings deserve much credit for the success of this project. They have worked hard, and we all have learned new things together.

TABLE OF CONTENTS

page

ACKNOWLEDGMENTS ii

LIST OF TABLES vi

LIST OF FIGURES viii

ABSTRACT x

CHAPTERS

1 INTRODUCTION AND LITERATURE REVIEW 1

Introduction 1
Belonolaimus longicaudatus 2
Northeast Florida Agriculture Production 7
Objectives 10

2 GENERAL MATERIALS AND METHODS USED IN THE FIELD STUDY 11

Introduction 11
Planting Site 11
Experimental Design 12
General Production Practices 16

3 YIELD REDUCTION AND ROOT DAMAGE OF COTTON INDUCED BY *BELONOLAIMUS LONGICAUDATUS* 21

Introduction 21
Materials and Methods 22
Results 26
Discussion 31

4 POPULATION DYNAMICS OF *BELONOLAIMUS LONGICAUDATUS* IN A COTTON PRODUCTION SYSTEM 33

Introduction 33
Materials and Methods 34
Results 39
Discussion 43

5 DAMAGE FUNCTION AND ECONOMIC THRESHOLD FOR *BELONOLAIMUS LONGICAUDATUS* ON POTATO 46

Introduction 46
Materials and Methods 47
Results 50
Discussion 54

6 THE PATHOGENICITY OF *BELONOLAIMUS LONGICAUDATUS* ON POTATO 56

Introduction 56
Materials and Methods 57
Results 59
Discussion 62

7 EVALUATION OF SORGHUM-SUDANGRASS AND VELVETBEAN COVER CROPS BASED ON THEIR EFFECTS ON *BELONOLAIMUS LONGICAUDATUS*, OTHER PLANT- PARASITIC NEMATODES, AND POTATO YIELDS 66

Introduction 66
Materials and Methods 67
Results 70
Discussion 76

8 EVALUATION OF POTATO-COTTON CROPPING SYSTEMS BASED ON THEIR EFFECTS ON *BELONOLAIMUS LONGICAUDATUS*, OTHER PLANT-PARASITIC NEMATODES, AND CROP YIELDS 80

Introduction 80
Materials and Methods 81
Results 85
Discussion 90

9 SUMMARY 92

REFERENCES 98

BIOGRAPHICAL SKETCH 106

LIST OF TABLES

Table		page
2-1	Cropping system treatments used in the *Belonolaimus longicaudatus* field study carried out at the Yevington Farm near Hastings, Florida in 1996 to 1998	15
2-2	Planting and harvest dates for all the crops grown in the *Belonolaimus longicaudatus* field study carried out at the Yevington Farm near Hastings, Florida in 1996 to 1998	19
3-1	Results of stepwise multiple-regression analysis of cotton yield on initial population densities of all plant-parasitic nematodes present at the site of the *Belonolaimus longicaudatus* field study at the Yevington Farm near Hastings, Florida in 1997 and 1998	27
4-1	Treatments used to modify population densities of *Belonolaimus longicaudatus* for the population increase study	36
4-2	Length of clean fallow treatments (days between Pf and Pi sampling) and number of observations per treatment used in the population decline study	38
5-1	Results of stepwise multiple-regression analysis of potato yield on initial population densities of all plant parasitic nematodes present in the field site in 1997 and 1998	51
5-2	Economic thresholds for *Belonolaimus longicaudatus* on potato	53
7-1	Host status of cover crops for the nematodes present in the field site	71
7-2	Nematode population densities in January, at the beginning of the potato season, as influenced by the summer cover crop treatments	73

7 3 Effects of cover crop treatments on potato yield (kg/ha) by class size 75

8-1 Effect of cropping systems on population densities of plant-parasitic nematodes assayed in January each year 86

8-2. Effects of cropping system and nematicide treatments from the previous 1 or 2 years on potato yields (kg/ha) 88

8-3 Cotton treatment means for 1997 and 1998 89

9-1 Gross profit associated with different cropping system-nematicide treatment combinations during 1997 and 1998 96

LIST OF FIGURES

Figure		page
2-1	Generalized plot map of one of the beds from the *Belonolaimus longicaudatus* field study carried out at the Yelvington Farm	13
3-1	Regression of seed cotton yield on population density of *Belonolaimus longicaudatus* at planting in 1997 and 1998	29
3-2	Reduction of lengths of roots with diameters < 0.25 mm (A), 0.25 to 0.5 mm (B) and 0.5 to 1.0 mm (C) in response to increasing inoculation densities of *Belonolaimus longicaudatus*	30
4-1	Quadratic regression of *Belonolaimus longicaudatus* final population density (Pf) per 130 cm^3 of soil on the initial population density (Pi) per 130 cm^3 of soil on cotton	40
4-2	Linear regression of ln (x + 1) transformed final population density (Pf) per 130 cm^3 of soil on ln (x + 1) transformed initial population density (Pi) per 130 cm^3 of soil for *Belonolaimus longicaudatus* on cotton	41
4-3	Population decline model for *Belonolaimus longicaudatus* during clean fallow	42
5-1	Damage functions for *Belonolaimus longicaudatus* on potato in 1997 and 1998	52
6-1	Regression of root lengths with increasing diameter ranges on inoculation density of *Belonolaimus longicaudatus*	61
6-2	Regression of potato tuber weights > 20 g on inoculation density of *Belonolaimus longicaudatus* per 130 m^3 of soil from each of two trials	63
6-3	Effect of inoculation density of *Belonolaimus longicaudatus* per 130 cm^3 of soil on tuber shape and brightness	64

7-1. Effects of cover crops on population changes of *Belonolaimus longicaudatus* in potato production over 3 years without nematicide application 74

7-2. Potato yield contrasts between cover crop treatments for plots receiving the same nematicide treatments 77

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of
the Requirements for the Degree of Doctor of Philosophy

HOST-PARASITE RELATIONS AND MANAGEMENT OF *BELONOLAIMUS LONGICAUDATUS* ON POTATO AND COTTON

By

William T. Crow

August 1999

Chairman: D. W. Dickson
Major Department: Entomology and Nematology

Belonolaimus longicaudatus, sting nematode, is a serious pathogen on many important agricultural crops in northeast Florida. Potato (*Solanum tuberosum*) is the most common crop grown in this region, however during the 1990s cotton (*Gossypium hirsutum*) was introduced. As a result, it is important to understand the host-parasite relations of sting nematodes on both of these crops. Field experiments were conducted during 1996 to 1999 to study these host-parasite relations and to evaluate management of *B. longicaudatus* under different cropping systems. The damage to potato and cotton induced by *B. longicaudatus* was quantified by damage functions and the economic thresholds were derived from these damage functions. The economic thresholds for *B. longicaudatus* on potato and cotton were 3 and 5 nematodes/130 cm^3 of soil for potato and cotton, respectively. In population dynamics studies of *B. longicaudatus* in cropping

systems involving potato and cotton *B. longicaudatus* densities increased readily on both crops. When cotton was monocropped, with clean fallow between cotton crops, a net decline in sting nematode population densities was observed. Rotation of potato and cotton did not effect population densities of *B. longicaudatus*, crop yields, or gross profits compared to monocropping of either crop ($P < 0.05$). Double-cropping of potato and cotton resulted in the highest profitability of any cropping system when *B. longicaudatus* was managed on potato with 1,3-dichloropropene and on cotton with aldicarb ($P < 0.05$). Population densities of *B. longicaudatus* were higher on potato when sorghum-sudangrass (*Sorghum bicolor* × *S. arundinaceum*) was used as a summer cover crop than when velvetbean was used as a cover crop ($P < 0.05$), but potato yields were unaffected ($P < 0.05$).

CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

Introduction

The research reported herein was conducted largely at the University of Florida Agricultural Research and Education Center, Hastings, in northeast Florida. The northeast Florida agricultural region, is an ideal habitat for *Belonolaimus longicaudatus*, the sting nematode, and is the only important potato (*Solanum tuberosum* L.) production region in the world in which *B. longicaudatus* is abundant (Brodie, 1998). Cotton (*Gossypium hirsutum* L.) is a new crop to the region, and also is not commonly grown in regions infested with *B. longicaudatus* (Starr 1998). The production of potato and cotton in the same production system is not a common practice.

Belonolaimus longicaudatus has been reported as a pathogen of both potato (Weingartner et al, 1977, Weingartner et al , 1978) and cotton (Graham and Holdeman, 1953). However, no published data exist on the economic threshold densities based on damage functions, nor is there data on the population dynamics for *B. longicaudatus* on potato or cotton. Additionally, knowledge is lacking on the changes in *B. longicaudatus* population densities in cropping systems involving either rotation or double-cropping of cotton with potato.

Damage functions relate expected reductions in yield to nematode population densities, usually to the initial population density (Pi) of the nematodes (McSorley and

Duncan, 1995). The economic threshold population density can be determined from the damage function. The economic threshold is the population density at which the expected reduction in revenue caused by nematodes is sufficient to offset the variable cost of management (Ferris, 1978). If economic threshold population densities are known, recommendations for management can be made from results of soil assays. This information helps avoid unnecessary yield reductions or nematicide treatments, and helps maximize profit to the grower.

Mathematical models of population dynamics also can be useful tools in nematode management. Population dynamics models can be used to estimate changes in nematode population densities over time with different cropping systems. Different cropping systems then can be evaluated for viability relating to nematode management (McSorley, 1998) and appropriate cropping systems selected to minimize nematode damage and nematicide applications (Noe, 1998).

<u>*Belonolaimus longicaudatus*</u>

<u>Taxonomy</u>

The genus *Belonolaimus* was established by Steiner in 1949. The type species, *B. gracilis*, was collected from the rhizosphere of a pine tree near Ocala, Florida (Steiner 1949). Over the next several years *B. gracilis* was reported to damage strawberry, celery, and corn in Florida (Christie et al., 1952), peanut in Virginia (Owens, 1951), and cotton, soybean, and cowpea in South Carolina (Graham and Holdeman, 1953).

Rau (1958) described a second species of *Belonolaimus* which he named *B. longicaudatus*. Two major morphological differences separating the two species are that

B. longicaudatus has a shorter tail and a longer stylet than that of *B. gracilis* (Rau, 1958). Rau (1958) further noted that *B. longicaudatus* was the more common species. In fact, no published reports of *B. gracilis* other than Steiner's (1949) original description exist. It is now generally accepted that all the reports of *Belonolaimus* sp. damaging agricultural crops in the southeastern United States are *B. longicaudatus* rather than *B. gracilis* (Perry and Rhoades, 1982; Smart and Nguyen, 1991).

Rau later described three additional species of *Belonolaimus*: *B. euthychilus*, *B. maritimus*, and *B. nortoni* (Rau, 1963). Currently, in addition to the above-mentioned species, the genus includes *B. anama*, *B. jara*, *B. lineatus*, and *B. lolii* (Fortuner and Luc, 1987). The genus *Belonolaimus* was moved several times into different family and subfamily groups. The taxonomic placement for *B. longicaudatus* in the phylum Nemata currently is: order Tylenchida, suborder Tylenchina, superfamily Tylenchoidea, family Belonolaimidae, subfamily Belonolaiminae, genus *Belonolaimus*, species *longicaudatus* (Fortuner and Luc, 1987).

The host range of *B. longicaudatus* is extensive and includes horticultural, agronomic, and ornamental crops (Bekal and Becker, 1998; Perry and Rhoades, 1982; Smart and Nguyen, 1991). Several studies suggest that physiological races of *B. longicaudatus* with different host ranges exist (Abu-Gharbieh and Perry, 1970; Robbins and Barker, 1973). Additionally, populations of *B. longicaudatus* from North Carolina and Georgia were found to differ in morphology from each other and from Rau's description of *B. longicaudatus* (Robbins and Hirschmann, 1974). Matings between these two populations resulted in few, nonfertile offspring (Robbins and Hirschmann,

1974). This led Robbins and Hirschmann (1974) to suggest that these populations may be different species. Thus it appears that the taxonomy of *B. longicaudatus* from the southeastern United States is not yet fully resolved.

Biology

Belonolaimus longicaudatus is endemic to the coastal plains of the southeastern United States. It has been found as far north along the Atlantic Coast as New Jersey (Myers, 1979), and as far west along the Gulf Coast as Texas (Norton, 1959), but is most common in Florida (Perry and Rhoades, 1982). Soil texture is apparently a major factor influencing the distribution of *B. longicaudatus* both within the soil horizon, and geographically (Brodie, 1976; Robbins and Barker, 1974). Reproduction of *B. longicaudatus* is minimal in soils with < 80% sand content or > 10% clay content (Robbins and Barker, 1974). The United States Golf Association (USGA) specifications for putting green construction require 90% sand content in the root zone layer (Anonymous, 1993) thereby providing an ideal habitat for *B. longicaudatus*. Therefore, it is not surprising that *B. longicaudatus* has become established outside its natural geographic range in putting greens on golf courses in Bermuda, Puerto Rico, the Bahamas, and California through introduction on infested planting material (Perry and Rhoades, 1982; Mundo-Ocampo et al., 1994).

Belonolaimus longicaudatus is a bisexual species with males generally accounting for 40% of the population (Smart and Nguyen, 1991). Reproduction is exclusively via amphimixis (Huang and Becker, 1999). A female lays eggs repeatedly if food is readily available, with each female laying about 130 eggs in 90 days (Huang and Becker, 1999).

The eggs are laid in pairs, with one egg coming from each ovary (H. Han, unpubl. data). The lifecycle of *B. longicaudatus* is completed in 24 days at 28 °C on excised roots of corn grown in vitro (Huang and Becker, 1997; Huang and Becker, 1999).

A migratory ectoparasitic nematode, *B. longicaudatus* usually remains in the soil and feeds by inserting its stylet deep into host tissue to withdraw cellular contents (Huang and Becker, 1997). *Belonolaimus longicaudatus* has no reported long-term survival stage (i.e., cysts) and has not been shown to undergo anabiosis or diapause. Therefore, the presence of a suitable host plant is necessary for its survival.

Temperature was found to influence reproduction of *B. longicaudatus* (Boyd and Perry, 1971; Robbins and Barker, 1974). Reproduction in the field was higher at 29 °C than 27 °C or 35 °C (Boyd and Perry, 1971). In controlled temperature studies reproduction was higher at 25 °C or 30 °C than at 20 °C or 35 °C (Robbins and Barker, 1974). Soil moisture, while not as well quantified as temperature, also has been implicated to influence the activity of *B. longicaudatus* with reproduction being higher at 7% soil moisture than at 30% or 2% (Robbins and Barker, 1974).

Relationships with Cotton

Belonolaimus longicaudatus was first reported as a pathogen of cotton, as *B. gracilis*, in 1953 (Graham and Holdeman, 1953). It was associated with damaged plants in the field, and its pathogenicity was verified in inoculation tests in the greenhouse. Symptoms were described as "dark shrunken lesions along the root axis or at the root tip ... proliferation of new roots above the point of attack or 'stubby root' symptoms was not observed in cotton."

In addition to the ability to cause direct damage to cotton roots, *B. longicaudatus* also is reported to be involved in disease complexes. The nematode has been shown to interact synergistically with *Fusarium oxysporum* f. sp. *vasinfectum*, the causal agent of fusarium wilt of cotton. The percentage of wilted plants was higher for cotton plants inoculated with both *B. longicaudatus* and *F. oxysporum* than for plants inoculated with either of the pathogens alone (Holdeman and Graham, 1954, Minton and Minton, 1966, Yang et al., 1976).

The host status of cotton for *B. longicaudatus* has been reported to vary with cultivar. 'Coker 100WR' cotton was a good host for a population of *B. longicaudatus* from South Carolina (Holdeman and Graham, 1953), whereas 'Stoneville 7A' cotton was a poor host for *B. longicaudatus* isolates from North Carolina and Georgia (Robbins and Barker, 1973). In a Tifton, Georgia field study high population densities of *B. longicaudatus* (> 150 nematodes/100 cm^3 of soil) were maintained throughout the growing season on 'Coker 413-67' cotton (Johnson, 1970). In a 7-year study at the same locality, population densities of *B. longicaudatus* declined from 228 to 42 nematodes/100 cm^3 of soil during the first season of 'Georgia King' cotton and remained ≤ 25 nematodes/100 cm^3 of soil in subsequent years after repeated planting (Johnson et al., 1998).

Relationships with Potato

Belonolaimus longicaudatus, which was first reported to damage potato in 1977 (Weingartner et al., 1977), is only reported as damaging potato in northeast Florida (Brodie, 1998). This is probably because other potato production regions do not have a

suitable habitat for *B. longicaudatus*. The damage to potato was established when potato yields and tuber defect indices were regressed on population densities of different nematode species. *Belonolaimus longicaudatus* was found to have the highest negative correlation with yields, and the highest positive correlations with tuber defects (Weingartner et al., 1977, Weingartner et al., 1978).

Cover Crops

The use of cover crops or rotational crops during the season(s) between economically valuable crops has been shown to impact population densities of *B. longicaudatus* (Reddy et al., 1986; McSorley and Dickson, 1995; McSorley and Dickson, 1989b; Rhoades, 1976; Rhoades, 1983; Weingartner et al., 1993). Population densities can either increase or decrease, depending on the crops planted. Sorghum-sudangrass hybrids (*Sorghum bicolor* (L.) Moench × *S. arundinaceum* (Desv.) Stapf var. *sudanense* (Stapf) Hitchc.) are good hosts for *B. longicaudatus*, and population densities of the nematode can increase readily on them (McSorley and Dickson, 1995; Perez, 1997; Rhoades, 1983; Weingartner et al., 1993). Velvetbean (*Mucuna pruriens* (Walloch ex Wight) Baker ex Burck, syn. *M. deeringiana*) is a non host and its planting has been shown to decrease population densities of *B. longicaudatus* (Reddy et al., 1986; McSorley and Dickson, 1995).

Northeast Florida Agriculture Production

The northeast Florida agricultural region is located in three counties between the Atlantic coast and the St. Johns River: Putnam, St. Johns, and Flagler counties. Soils in the region are sandy flatwoods series and are generally composed of 90 to 95% sand, <

5% silt, < 2.5% clay, < 2% organic matter (Weingartner et al., 1993). These soils provide ideal habitat for *B. longicaudatus*, which has been found almost universally distributed in commercial agriculture fields in the region (R. P. Esser, unpubl. data, Nguyen and Smart, 1975).

Potato

Potato has been the major crop grown in northeast Florida throughout the 20th century. In 1996, 11,138 ha of potato were grown in northeast Florida. The area planted to potato declined to 8,910 ha in 1999 (Anonymous, 1999). About 85% of the potatoes grown in the region are used for making potato chips, and the most common chipping variety 'Atlantic' is grown on 80% of the hectares planted to potato (D. P. Weingartner pers. comm.). Potato is usually planted from December to early February, and harvested from April to early June.

Because of the high sand content of the soil in northeast Florida, the soil has a low water-holding potential and requires irrigation. The region also is subject to heavy rainfall events which necessitate drainage. The potato fields are arranged to provide lateral water canals (water furrows) that serve to provide both seepage irrigation and drainage (Campbell et al., 1978; Rogers et al., 1975). These water furrows are placed every 17 m and provide space for a planting bed of 16 crop rows with 102 cm between rows.

Plant-parasitic nematodes and associated disease complexes are important potato production problems in the region (Weingartner and Shumaker, 1983, Weingartner et al., 1993). Nearly all of the potato fields in the region are treated with nematicides each year

(Weingartner and Shumaker, 1983). The most commonly used nematicides are the soil fumigant 1,3-dichloropropene and the nonvolatile carbamate aldicarb. These chemicals are used either alone or in combination for management of plant parasitic nematodes, corky ringspot, and bacterial wilt (Weingartner and Shumaker, 1983, Weingartner and Shumaker, 1990a, Weingartner and Shumaker, 1990b, Weingartner and Shumaker, 1990c, Weingartner et al., 1993).

Following potato, a cover crop is usually grown during the summer. Several cover crops have been used in the past, including volunteer weeds, sesbania (*Sesbania exaltata*), and sorghum-sudangrass. However, the latter has been the most commonly used cover crop during the last 20 years (Weingartner et al., 1993). During the summer the cover crop prevents soil erosion from heavy and frequent rains. The cover crop residues also help prevent the erosion of the planted rows during the early part of the potato season (Myhre, 1957).

Sorghum sudangrass is valued because of its high biomass production and crop residues. Evidence exists that sorghum sudangrass also may inhibit some soilborne pathogens such as *Ralstonia solanacearum* (syn. *Pseudomonas solanacearum*) and *Meloidogyne incognita* (D. P. Weingartner, unpubl. data). At least part of the disease suppression is attributed to suppression of weeds that act as alternative hosts for the pathogens (D. P. Weingartner, unpubl. data). Because sorghum-sudangrass is a good host for *B. longicaudatus* (Rhoades, 1983, Weingartner et al., 1993), there is concern that its use may increase population densities of *B. longicaudatus* and negatively affect the subsequent potato crop (Weingartner et al., 1993).

Cotton

During the past decade, potato prices in Florida have declined steadily from a high of $0.45/kg in 1991 to $0.28/kg in 1997 (Anonymous, 1999). During the same period, cotton prices increased from $1.21/kg of cotton in 1991 to $1.63/kg of cotton in 1997 (Anonymous, 1999). Therefore, growers in the region became interested in cotton as an alternative crop to potato. Approximately 810 ha of cotton were planted in 1996 near Hastings, an area where cotton had not been grown previously (A. Tilton, Putnam County Extension Director, pers. comm.).

Objectives

The objectives of this research were to

1. quantify yield reductions in cotton and potato induced by *B. longicaudatus*

2. determine economic threshold densities for *B. longicaudatus* on cotton and potato

3. model the population dynamics of *B. longicaudatus* in cotton and potato production systems

4. determine the pathogenicity of *B. longicaudatus* on potato

5. evaluate the viability of rotation and double-cropping of cotton with potato based on population densities of *B. longicaudatus* and crop yield

6. evaluate sorghum sudangrass and velvetbean as cover crops for potato production

CHAPTER 2
GENERAL MATERIALS AND METHODS USED IN THE FIELD STUDY

Introduction

A 90-plot field experiment was conducted annually from February 1996 through January 1999 at the University of Florida Agricultural Research and Education Center Yelvington Farm near Hastings, Florida. The objectives of this study were to

1 quantify yield losses to potato (*Solanum tuberosum* L.) and cotton (*Gossypium hirsutum* L.) caused by *Belonolaimus longicaudatus* Rau (sting nematode)

2 determine the economic threshold densities for *B. longicaudatus* on potato and cotton

3 model population dynamics of *B. longicaudatus* in potato and cotton production systems

4 evaluate the viability of rotation and double-cropping of cotton with potato based on population densities of *B. longicaudatus* and crop yield

5 evaluate sorghum sudangrass (*Sorghum bicolor* (L.) Moench × *S. arundinaceum* (Desv.) Stapf var. *sudanense* (Stapf) Hitchc.) and velvetbean (*Mucuna pruriens* (Walleh ex Wight) Baker ex Burck, syn. *M. deeringiana*) as cover crops for potato production

Planting Site

Pathogens

The soil at the field site represents a complicated pathosystem. Plant-parasitic nematodes present at this site include *B. longicaudatus*, *Criconemella* sp. *Dolichodorus heterocephalus*, *Hemicycliophora* sp., *Meloidogyne incognita* race 1, *Paratrichodorus minor*, *Pratylenchus brachyurus*, *P. zeae*, and *Tylenchorhynchus* sp. Other soilborne

pathogens present at the field site include fungal (*Fusarium oxysporum*, *Pythium* sp., *Rhizoctonia solani*, *Sclerotium rolfsii*, *Verticillium dahliae*), bacterial (*Ralstonia solanacearum*), and viral (tobacco rattle virus) pathogens.

Physical Properties

Soil at the field site is an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf). Soil texture 20 to 25-cm deep was determined by the hydrometer method (Bouyoucos, 1936) and found to be composed of 95% sand, 2% silt, and 3% clay; < 1% organic matter; pH 6.5 to 7.0.

Plot Layout

The experiment was conducted on five beds, with 16 rows per bed. Rows were ridged (30.5 cm high), and were spaced 102 cm apart. Plots were 9 m long and 4 m wide. The inner two rows of each plot were used for data collection, while the outer two rows were guard rows. Two clean fallow rows were maintained between adjacent plots and 3 m of clean fallow were maintained between plots in the same rows. Seepage irrigation was provided by manipulation of the water table via lateral water canals placed at 17 m intervals (Campbell et al., 1978; Rogers et al., 1975).

Experimental Design

The experiment was arranged in a split-plot design with cropping systems replicated five times as whole-plots, and subplots consisting of nematicide treatments and an untreated control. A generalized plot diagram illustrating a single replication of the experimental design is shown in Fig. 2-1.

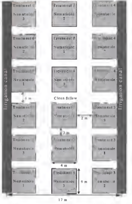


Figure 2.1. Generalized plot diagram of a single replication from the *Belonolaimus longicaudatus* field study carried out at the Yelvington Farm

Cropping Systems

The six cropping system treatments evaluated were: (i) 3 years of winter-spring potato followed by sorghum-sudangrass, representing the standard cropping practice for potato in the area, (ii) 3 years of monocropped cotton grown during the summer-fall, (iii) potato and cotton in a 1 year rotation, (iv) 2 years of cotton followed by potato and sorghum-sudangrass the third year, (v) winter-spring potato double-cropped with summer fall cotton for 3 years, and (vi) potato followed by a summer cover crop of velvetbean for 3 years. These cropping systems are shown in tabular form in Table 2-1

Nematicide Treatments

Nematicide treatments used in this study were aldicarb (15G), 1,3-dichloropropene (1,3-D) and an untreated control. Potato and cotton were treated with nematicides, whereas sorghum-sudangrass and velvetbean cover crops were untreated. Each nematicide treated plot received the same treatment each year during this study. Plots double-cropped to potato and cotton were treated twice each year. Cotton following both 1,3-D, and aldicarb treated potato was treated with aldicarb.

Aldicarb was applied in a 25-cm-wide band with an electric-driven Gandy applicator (Gandy Company, Owatonna, MN) at the rate of 3.4 kg a.i./ha (34 g/100 m of row) for potato. Aldicarb was banded directly over potato seed pieces in the opened rows and was incorporated lightly with soil as the rows were closed. For cotton, the rows were flattened with a stalk-chopper and aldicarb was applied in a 25-cm wide band at the rate of 1.7 kg a.i./ha (17 g/100 m of row). Incorporation of the chemical was obtained when the rows were reshaped with bedding disks for planting. 1,3-

Table 2-1 Cropping system treatments used in the *Belonolaimus longicaudatus* field study carried out at the Yelvington Farm near Hastings, Florida during 1996 to 1998

	1996		1997		1998	
Cropping system	Winter-spring	Summer-fall	Winter-spring	Summer-fall	Winter-spring	Summer-fall
1	P[a]	S	P	S	P	S
2	F	C	F	C	F	C
3	P	C	P	C	P	C
4	F	C	P	S	F	C
5	F	C	F	C	P	S
6	P	V	P	V	P	V

[a]P = Potato S = Sorghum sudangrass. C = Cotton. V = Velvetbean. F = Clean fallow

Dichloropropene was injected with a gravity-flow applicator 25 to 30 cm deep at 56 liters/ha (570 ml/100 m of row) with a single chisel per row. Applications of 1,3-dichloropropene were made 3 weeks before planting of either potato or cotton.

General Production Practices

Fertilization

Potato crops were fertilized each year at planting with 1,120 kg/ha (broadcast) of a 14-2-12 (N-P_2O_5-K_2O) mixture. Nutrient rates were 157 kg/ha N, 10 kg/ha P, 112 kg/ha K, 23 kg/ha Mg, 45 kg/ha S, and trace amounts of other essential micronutrients.

The cotton fertilization program varied from 1996 to 1997/1998. In 1996, a 0-7-28 (N-P_2O_5-K_2O) mixture was applied preplant at the rate of 560 kg/ha (broadcast). Nutrient rates were 17 kg/ha P, 130 kg/ha K, 45 kg/ha S, 17 kg/ha Mg, 17 kg/ha Ca, and trace amounts of other micronutrients. After emergence, cotton was side-dressed with a 42-34-0 (N-P_2O_5-K_2O) solution at the rate of 70 liters/ha that added 28 kg/ha N and 10 kg/ha P. Two more side-dress applications of a 32-0-0 (N-P_2O_5-K_2O) solution were applied later in the season at rates of 93.5 liters/ha and 145 liters/ha. These supplied 29 kg/ha N and 43 kg/ha N for the respective applications.

During the 1996 growing season, when all the K was added at the beginning of the season, the cotton plants showed symptoms of K deficiency (Watkins, 1981). This problem was alleviated in 1997 and 1998 by applying side-dress applications during the growing season.

A 5-13-9 (N-P_2O_5-K_2O) mixture was applied to cotton and incorporated at planting in 1997 and 1998 at the rate of 560 kg/ha. Nutrient rates were 28 kg/ha N, 32

kg/ha P, 47 kg/ha K, and trace amounts of micronutrients. Plots were side-dressed twice with a 6-0-20 (N-P_2O_5-K_2O) mixture at the rate of 672 kg/ha. Side-dress applications yielded 40 kg/ha N, and 112 kg/ha K. A final side-dress application of 33-0-0 at the rate of 118 kg/ha was applied in 1997.

Fertilizer was applied to the sorghum-sudangrass each year. At planting 1,120 kg/ha of a 14-2-12 mixture was applied to soil and incorporated. Sorghum-sudangrass received a side-dress application of N at the rate of 56 kg/ha about 1 month after planting each year. In 1996 no fertilizer was applied to the velvetbean. However, because of poor growth in 1996, 1,120 kg/ha of a 14-2-12 mixture was applied to soil and incorporated at planting in 1997 and 1998 for velvetbean.

Pesticides

For weed control on potato a mixture of the herbicides metolachlor and pendimethalin was applied preemergence (Hochmuth et al., 1996). For weed control on cotton a mixture of the herbicides pendimethalin and fluometron was applied 3 days after planting (Colvin and Brecke, 1998).

Insects found attacking potato in these trials were primarily *Leptinotarsa decemlineata* (Colorado potato beetle) and *S. eridania* (southern armyworm). These pests were managed with of *B. thuringiensis* and phthalic glycerol alkyl resin (Johnson, 1997).

Insects found attacking cotton included *Spodoptera eridania* (southern armyworm), *Bemisia argentifolii* (silverleaf whitefly), *Euschistus servus* (brown stink bug), and *Tetranychus urticae* (two spotted spidermite). These pests were managed with

acephate, *Bacillus thuringiensis* cyhalothrin, dicofol, diflubenzuron, esfenvalerate imidacloprid, spinosyn, and thiodicarb (Selman 1998).

Foliar fungal pathogens of potato *Phytophthora infestans* and *Alternaria solani* were managed by applications of mancozeb and chlorothalonil (Hochmuth et al., 1996)

Other Chemicals

Cotton was treated with mepiquat chloride to prevent excessive vegetative growth of cotton plants (Wright and Sprenkel, 1996) Cotton also was sprayed of ethephon to facilitate boll ripening and tribufos to dessicate foliage before harvest (Wright and Sprenkel, 1996)

Planting and Harvest

Planting and harvest dates for all crops are listed in Table 2 2 Forty-five potato seed pieces 5 to 6.5 cm-diam were hand-placed in each row at 20-cm spacing between pieces. Potato tubers were harvested with a single-row mechanical harvester, graded, and mechanically sized and weighed.

Cotton seeds were planted at 10-cm spacing, and following emergence were thinned to 20-cm spacing between seedlings Cotton was harvested with a single-row mechanical harvester, and weights of seed cotton yield were recorded.

Sorghum sudangrass and velvetbean were planted within 2 weeks of potato harvest each year Sorghum-sudangrass was planted mechanically with a two-row planter Velvetbean was planted manually Both cover crops were chopped down with a stalk chopper at harvest, and later incorporated into the soil by disking before planting the potato crop the following year

Table 2-2. Planting and harvest dates for all the crops grown in the *Belonolaimus longicaudatus* field study carried out at the Yelvington Farm near Hastings, Florida during 1996 to 1998

	1996		1997		1998	
Crop	Planting	Harvest	Planting	Harvest	Planting	Harvest
Potato	4 March	6 June	10 Feb	14 May	27 Feb	8 June
Cotton	26 April	22 Oct	22 May	17 Oct	29 June	9 Dec
D-C Cotton[a]	13 June	11 Dec	22 May	17 Oct	29 June	9 Dec
Sorghum-sudangrass	13 June	22 Oct	22 May	7 Oct	29 June	26 Oct
Velvetbean	13 June	22 Oct	22 May	7 Oct	29 June	26 Oct

[a]Cotton double-cropped with potato

Cultivars

The potato cultivar Atlantic, used throughout this study, is the major chipping potato used for the region, and is grown on 80% of the potato hectarage (D. P. Weingartner, pers. comm.). 'DPL 50' cotton was planted in 1996. This cultivar was poorly adapted to northeast Florida conditions (D. Colvin, unpubl. data), so 'DPL 5415' cotton was planted in 1997 and 1998.

CHAPTER 3
YIELD REDUCTION AND ROOT DAMAGE OF COTTON INDUCED BY *BELONOLAIMUS LONGICAUDATUS*

Introduction

Belonolaimus longicaudatus Rau (sting nematode) is a destructive pathogen on a variety of crops (Perry and Rhoades, 1982; Smart and Nguyen, 1991). While it can be devastating to crops where it is found, geographic distribution of *B. longicaudatus* is limited primarily to the coastal plains of the southeastern United States. Apparently soil texture greatly influences the distribution of *B. longicaudatus*; it is found predominantly in soils composed of $\geq$80% sand and < 10% organic matter (Robbins and Barker, 1974).

Belonolaimus longicaudatus was first identified as a pathogen of cotton (*Gossypium hirsutum* L.) by Graham and Holdeman (1953), who reported severe yield reductions and root damage in field and greenhouse tests. They described symptoms on cotton roots as "shrunken lesions along the root axis or at the root tip." Sting nematode was later reported to cause stubby root symptoms on 'DPL 50' cotton (Crow et al., 1997). Sting nematode also was found to increase the severity of Fusarium wilt of cotton in greenhouse tests (Holdeman and Graham, 1954; Minton and Minton, 1966; Yang et al., 1976).

The existence of different physiological races of *B. longicaudatus* has been suggested because the host range of populations from different locations have been

shown to differ substantially (Abu-Gharbieh and Perry, 1970; Robbins and Barker, 1973). The host status of cotton for *B. longicaudatus* has varied in experiments conducted by different researchers. 'Coker 100WR' cotton was a good host for *B. longicaudatus* from South Carolina (Holdeman and Graham, 1953), but 'Stoneville 7A' cotton was a poor host for populations from North Carolina and Georgia (Robbins and Barker, 1973).

Although *B. longicaudatus* has long been identified as a severe pathogen of cotton, there has been little research devoted to this host-pathogen combination. This is explained by the lack of cotton production on soils conducive to sting nematode. Recent surveys of cotton fields in South Carolina and Georgia found the incidence of infestation with *B. longicaudatus* to be < 1% and 0.3%, respectively (Baird et al., 1996; Martin et al., 1994). A survey of nematodes in cotton fields in Florida found no sting nematodes in any sampled fields (Kinloch and Sprenkel, 1994). If cotton production expands into soils with high sand content conducive to *B. longicaudatus*, sting nematode is expected to become a significant problem (Starr, 1998). The objectives of this study were to quantify reductions in yield and root systems in response to increasing population densities of *B. longicaudatus*.

Materials and Methods

Yield Reductions in the Field

Yield reductions caused by *B. longicaudatus* in the field were quantified in a 2-year trial carried out at the University of Florida Agricultural Research and Education Center at Hastings, Florida Yelvington Farm in 1997 and 1998. The site selected was naturally infested with *B. longicaudatus*, *Meloidogyne incognita* race 2, *Paratrichodorus*

minor, *Pratylenchus brachyurus*, *P. zeae*, *Tylenchorhynchus* sp., *Criconemella* sp., *Dolichodorus heterocephalus*, and *Hemicycliophora* sp. Soil at the research site is an Ellzey fine sand (sandy, siliceous hyperthermic Arenic Ochraqualf) consisting of 95% sand, 2% silt, 3% clay < 1% organic matter; pH 6.5 to 7.0.

To study effects of sting nematode on cotton over a range of population densities, initial population densities (Pi) of *B. longicaudatus* in 25 field plots were modified as follows. Twenty plots were planted to cotton following 8 months of clean fallow. Ten of these plots were fumigated 3 weeks before planting with 1,3-dichloropropene (1,3-D) at the broadcast rate of 56 liters/ha (570 ml/100 m row) applied with a single chisel per row. Fumigation resulted in low population densities at planting (Pi) of *B. longicaudatus*. The remaining 10 plots were untreated and had moderate Pi densities. To obtain high population densities (> 100 nematodes/130 cm^3 of soil), cotton was planted into an additional five plots where potato (a host for *B. longicaudatus*) had been grown the preceding winter. Only 1 week of fallow occurred between the potato and cotton crops in these plots, and no nematicides were used on either crop.

The experiment was carried out on ridged rows with 102 cm spacing between rows, and the plot area was watered by seepage irrigation (Campbell et al., 1978; Rogers et al., 1975). Field plots were four rows wide and measured 9 m long. Yield and nematode data were collected from the center two rows in each plot.

Nematode population densities in all plots were assayed 3 weeks following fumigation of plots receiving 1,3-D. Twelve cores (2.5-cm-diam.) were taken 20 cm deep from the center rows of each plot to form a composite sample. Nematodes were extracted

from a 130 cm^3 subsample using a modification of the centrifugal-flotation technique (Jenkins, 1964). Normally, during this process, soil is passed through a 2-mm sieve during the washing process to remove large debris. This step was omitted because *B. longicaudatus* is large enough to become ensnared by the sieve (McSorley and Frederick, 1991). Additionally the concentration of the sucrose solution was modified by doubling the amount of sugar to 0.908 kg of sugar per 1 liter of water. Numbers of all genera of plant-parasitic nematodes extracted were counted with the aid of an inverted light microscope at ×32 magnification.

'DPL 5415' cotton seeds were planted immediately following the collection of the P_i soil samples. Seedlings were thinned to 15 cm between plants following emergence. Planting dates were 22 May 1997 and 30 June 1998, and harvest dates were 17 October 1997 and 9 December 1998. Cotton was harvested with a single-row mechanical harvester, and seed cotton weights were recorded. Following harvest, cotton yield was regressed on initial population densities of all plant parasitic nematodes present by stepwise multiple-regression analysis (Ott, 1993). This provided for identification of plant-parasitic nematodes with strongest relationships to yield reductions (McSorley and Waddill, 1982). The multiple-regression analysis was performed using the SAS software program (SAS Institute, Cary, NC). Cotton yield also was regressed on P_i density of *B. longicaudatus* by simple linear regression to describe the relationship with this nematode alone. Linear regression was performed using the Excel software program (Microsoft Corporation, Redmond, WA).

Controlled Environmental Chamber Study

To quantify effects of increasing population densities of *B. longicaudatus* on cotton roots tests were conducted under controlled environmental conditions. These studies were carried out in two trials with the second trial having two additional inoculum levels.

A population of *B. longicaudatus* was collected from the Hastings field site and reared on bermudagrass (*Cynodon dactylon*) in pots filled with pasteurized soil in the greenhouse. Nematode inocula were extracted from greenhouse soil using a modified Baermann method (McSorley and Frederick, 1991). The inoculum consisted of mixed life stages of *B. longicaudatus* suspended in water.

Soil from the field site was autoclaved at 250 °C and 131 kPa for 45 minutes and then placed into 15-cm-diam. black plastic pots. Approximately 750 cm^3 of soil was added per pot. Nematode inoculum was pipetted into five 2 cm deep holes in the soil per pot at rates of 0, 20, and 60 nematodes/130 cm^3 of soil in the first trial and 0, 10, 20, 40, and 60 nematodes/130 cm^3 of soil in the second trial. Following addition of nematodes, three 'DPL 5415' cotton seeds were planted 1 cm deep into each pot and soil was wetted to 12% soil moisture (w/w).

The pots were then placed in controlled environmental chambers that were maintained at 28.5 °C. Soil moisture in each pot was kept between 5% and 12% (w/w). Plants were given 16 hours of light each day. Following emergence, seedlings were thinned to one per pot and grown for 40 days. The plants were removed and the soil was washed from the roots.

Each root sample was immersed in 150 ml water in plastic cups that had three drops of 1% methylene blue added. The stained roots were then placed into a glass-bottom tray and scanned using a HP ScanJet 2cx desktop scanner (Hewlett Packard, Boise, ID) to create a bitmap image of the roots (Kaspar and Ewing, 1997; Pan and Bolton, 1991). Bitmap images were imported into the GSRoot (Louisiana State University, Baton Rouge, LA) software program for analysis. This program is designed to measure root lengths and surface areas from scanned images. Root-diameter ranges of interest are entered into the program, which then gives individual measurements for roots of each diameter range. Diameter ranges measured were < 0.25 mm, 0.25 to 0.5 mm, 0.5 to 1.0 mm and > 1.0 mm. The root length measurements for each range were regressed on inoculation density of *B. longicaudatus* (Ott, 1993). Linear regression was performed using the Excel software program (Microsoft Corporation, Redmond, WA).

Results

Yield Losses in the Field

Sting nematodes had the greatest degree of association with cotton yield losses in the field, and no other nematodes were consistently associated with yield reductions during both years (Table 3-1). Separate linear regressions of cotton yield on Pi density of *B. longicaudatus* from the 2 years were tested for heterogeneity of the slopes (Freund and Littell, 1981). Because the slopes for the 2 years were not significantly different from each other ($P = 0.68$), data from the 2 years were combined into a single data set for further regression analysis. The association between Pi density of *B. longicaudatus* (x) and cotton yield (Y) for both years was described by the linear equation $Y = -18.36x +$

Table 3-4. Results of stepwise multiple-regression analysis of cotton yield on initial population densities of all plant parasitic nematodes present at the site of the *Belonolaimus longicaudatus* field study at the Yelvington Farm near Hastings, Florida in 1997 and 1998.

Nematode	1997		1998	
	R^2	Prob>F	R^2	Prob>F
Belonolaimus longicaudatus	0.76	0.0001	0.72	0.0001
Meloidogyne incognita	0.02	0.14	NS	NS
Paratrichodorus minor	NS[a]	NS	0.04	0.07
Pratylenchus spp.	NS	NS	NS	NS
Tylenchorhynchus sp.	0.04	0.05	NS	NS
Criconemella sp.	NS	NS	NS	NS
Dolichodorus heterocephalus	NS	NS	NS	NS
Hemicycliophora sp.	NS	NS	NS	NS

[a]NS = Regression was not significant at $P \leq 0.15$.

2848 with an $r^2 = 0.77$ ($P < 0.0001$) (Fig. 3-1). Damage to cotton plants at the seedling stage was severe at high Pi densities (Pi > 60). Following emergence, most seedlings growing in soil with high densities of *B. longicaudatus* suffered complete root destruction, ceased growing, and died. Surviving plants tended to be stunted and many lodged.

Controlled Environmental Chamber Study

The relationships between inoculation density of *B. longicaudatus* and root length are described by negative exponential equations for the different root diameter ranges (Fig. 3-2). In order to test for heterogeneity of slopes between trials, the data used in the exponential equations for root length measurements were log transformed (ln x) in order to linearize the slopes and allowed for heterogeneity of slopes to be statistically tested (Freund and Littell, 1981). Although the second trial had two additional inoculation rates, the slopes of the regression lines from the two trials were not different for roots with diameters of < 0.25-mm ($P = 0.12$). Therefore, the data from the two trials were combined into a single data set (Fig. 3-2A). The slopes between the two trials were found to be heterogeneous, with P values of 0.05, and 0.07, for roots with diameters of 0.25 ≤ 0.5 and 0.5 ≤ 1.0, respectively. Therefore, regression lines for both trials are shown separately for these diameter ranges (Figs. 3-2B, 3-2C).

Root lengths of all diameter ranges < 1.0 mm-diam. were reduced in response to increasing inoculation densities of *B. longicaudatus* ($P < 0.001$). The data were fitted using negative exponential equations (Fig. 3-2). Inoculation density of *B. longicaudatus* had no significant effect ($P \geq 0.05$) on roots with diameters > 1 mm.

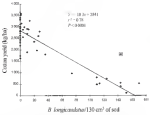


Figure 3 1 Regression of seed cotton yield on population density of *Belonolaimus longicaudatus* at planting in 1997 and 1998 Data from both years were combined for analysis ⊡ = Outlier plot i.e *B longicaudatus* in this plot had a high incidence of attachment by *Pasteuria* sp., an endospore-forming parasite of nematodes and was not included in the analysis

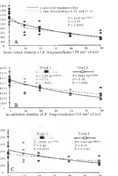


Figure 3-2. Reduction of lengths of roots with diameters < 0.25 mm (A), 0.25 to 0.5 mm (B), and 0.5 to 1.0 mm (C) in response to increasing inoculation densities of *Belonolaimus longicaudatus*. (A) The dashed line represents the linear change between inoculation rates of 0 to 10, and 10 to 80 *B. longicaudatus*/130 cm³ of soil. Data from both trials were combined for analysis. (B-C) Due to heterogeneity, data from each trial were subjected to analysis separately.

Roots < 0.25 mm-diam. growing in soil inoculated with the highest number of *B. longicaudatus* (60/130 cm^3 of soil) exhibited reductions in root lengths of 70% in comparison with those grown in uninoculated soil. The largest decrease in root length for roots of < 0.25 mm-diam. occurred between inoculation densities of 0 and 10 nematodes/130 cm^3 of soil with reductions of 39%. Reductions between the means of inoculation densities of 10 and 60 *B. longicaudatus*/130 cm^3 of soil followed a linear trend (Fig. 3-2A).

Discussion

Sting nematode is an aggressive pathogen of cotton that causes root damage and yield losses at low population densities. Of all the nematodes observed in the field study, only *B. longicaudatus* was consistently and significantly ($P \leq 0.05$) associated with yield decreases (Table 1). Inoculation rates of 60 *B. longicaudatus*/130 cm^3 of soil were capable of causing a 70% reduction in small diameter cotton roots (Fig. 3-2A).

Seinhorst (1965) proposed the concept of tolerance limits for damage to plants caused by root-feeding nematodes. According to the Seinhorst model there is a population density of nematodes below which plant damage is not observed. The Seinhorst model is useful because if the tolerance limit is known, management strategies can be designed to keep populations below this level (Barker and Noe, 1987; McSorley and Duncan, 1995). The field data indicate that the tolerance limit for *B. longicaudatus* on cotton occurs at a very low density, probably at < 15 nematodes/130 cm^3 of soil.

In the inoculation studies, population densities as low as 10 *B. longicaudatus*/130 cm^3 of soil caused nearly a 40% reduction in fine cotton roots. Current extraction

efficiency estimates for *B. longicaudatus* with the centrifugal-flotation method is 30% (McSorley and Frederick, 1991). This places 10 nematodes per 130 cm^3 of soil near the detection threshold from the field, and supports the field study findings of a low tolerance limit. Damage functions such as the one derived in this study may be useful in establishing economic thresholds dependent upon local conditions and costs (Ferris, 1978).

CHAPTER 4
POPULATION DYNAMICS OF *BELONOLAIMUS LONGICAUDATUS* IN A COTTON PRODUCTION SYSTEM

Introduction

Belonolaimus longicaudatus Rau (sting nematode) is a virulent pathogen of cotton (*Gossypium hirsutum* L.) (Graham and Holdeman, 1953, Crow et al., 1998) but host status of cotton to *B. longicaudatus* has varied in experiments using different cotton cultivars (Johnson, 1970, Johnson et al., 1998, Robbins and Barker 1973). *Belonolaimus longicaudatus* is limited primarily to soils with a high sand content (Robbins and Barker, 1974). Cotton is not typically grown in sandy soils, so surveys of cotton fields in the southeastern United States have rarely found *B. longicaudatus* associated with cotton (Baird et al., 1996. Kinloch and Sprenkel, 1994, Martin et al., 1994). However during the 1990s, high cotton prices led to expansion of cotton production into areas with favorable habitat for sting nematode. Cotton production in these areas, such as northeastern Florida, is expected to be limited by sting nematode (Starr, 1998).

Population increase and decline models are useful for predicting whether nematode problems will stabilize, increase, or decrease over time in a given production system (Ferris et al., 1994). These models give growers the tools with which to evaluate nematode management strategies not only for the current crop, but for the cropping system over time (Barker and Noe, 1987, Ferris et al., 1994). Using population dynamics

models, along with economic threshold population densities, the economic viability of the system can be evaluated. The economic threshold is defined as the value at which the expected increase in return per hectare is equal to the variable costs (e. g., nematicide and application costs) of management (Ferris, 1978). Neither population dynamics models or economic thresholds for *B. longicaudatus* in cotton production have been previously reported.

Population dynamics models for *B. longicaudatus* in a cotton production system were developed from data taken from a cropping system study in St. Johns County, Florida (Chapter 2). Economic thresholds for sting nematode on cotton were derived from damage functions and economic data. The population dynamics models and economic thresholds were used to evaluate the economic viability of cotton production in sting nematode-infested soil.

Materials and Methods

A 3-year field trial was conducted during 1996 through 1998 studying the population dynamics and plant damage of *B. longicaudatus* on potato and cotton (Chapter 2). Data collected from portions of this experiment during 1997 and 1998 are reported herein. The field site was located at the University of Florida Agricultural Research and Education Center, Yelvington Farm near Hastings, Florida. The site selected was naturally infested with *B. longicaudatus*, *Criconemella* sp., *Dolichodorus heterocephalus*, *Hemicycliophora* sp., *Meloidogyne incognita* race 1, *Paratrichodorus minor*, *Pratylenchus brachyurus*, *P. zeae*, and *Tylenchorhynchus* sp. The soil at this site is an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf) composed of 95%

sand, 2% silt, 3% clay; < 1% organic matter; pH 6.5 to 7.0. Twenty-five plots were planted to 'DPL 5415' cotton in 1997 and 1998. The initial population densities of *B. longicaudatus* in these plots were modified by cropping system, fallow, and nematicide application. The treatments are listed in Table 4-1.

Population Increases

In both 1997 and 1998 soil samples were collected at planting (Pi) and at harvest (Pf) of the cotton crop. Twelve 2.5-cm-diam. cores were collected from the two center rows of each four-row plot and composited. Nematodes were extracted from a 130 cm³ subsample using a centrifugal-flotation method (Jenkins, 1964), modified as reported previously (Chapter 3). Following extraction, nematodes were counted by the use of an inverted light microscope at ×32 magnification.

Models were developed quantitatively relating Pf with Pi density of *B. longicaudatus*. Separate models were developed using both nontransformed population data and data transformed with ln (x + 1) before analysis. Data from both years were combined into a single data set for analysis. The relationships of Pf to Pi were subjected to regression analysis (Ott, 1993) in which Pf densities were regressed on Pi densities, and ln (Pf + 1) transformed densities were regressed on ln (Pi + 1) transformed densities. Nontransformed population numbers were regressed using a quadratic model, and log transformed numbers were regressed using a linear model. Regression analysis was performed using the Excel software program (Microsoft Corporation, Redmond, WA). The carrying capacity for *B. longicaudatus* on cotton was defined as the maximum

Table 4-1 Treatments used to modify population densities of *Belonolaimus longicaudatus* for the population increase study. Population densities were modified by previous crop, length of fallow between crops, and nematicide application.

Treatment	Previous crop	Months of fallow	Nematicide
1	Cotton	7	Untreated
2	Cotton	7	1,3-D[a]
3	Sorghum-sudangrass	8	Untreated
4	Sorghum-sudangrass	8	1,3-D
5	Potato	< 1	Untreated

[a]1,3-Dichloropropene

expected Pf density as derived from the quadratic equation. Cotton was considered a good host if the linear regression line for the log transformed data was above the maintenance line, where ln (Pi + 1) = ln (Pf + 1).

<u>Population Decreases</u>

A population decline model for *B. longicaudatus* under clean fallow was derived from data collected from the same field experiment used for the population increase data (Chapter 2). Clean fallow periods of varying lengths were maintained as part of this experiment (Table 4-2). Nematode samples collected during the fall or early winter before fallow are considered as Pi samples for the fallow. Samples collected during the winter through early summer following fallow are considered as Pf samples for the fallow. Because the field experiment was not designed to study population declines, the number of days between sampling dates and the number of data points for each sampling date are not balanced. A total of 245 data points from 14 different fallow periods were used (Table 4-2). Because of increased error associated with low Pi densities, only plots with ≥50 sting nematodes/130 cm^3 of soil at the initial sampling date were included in this study.

The proportion of the sting nematodes remaining after the fallow periods was determined by the Pf/Pi ratio, where Pf = population density after fallow and Pi = population density before fallow. Regression of the raw proportions cannot take into account the experimental error associated with sampling. Therefore, mean values for each fallow period were determined and assigned as many times as there were

Table 4-2 Length of clean fallow treatments (days between Pf and Pi sampling) and number of observations per treatment used in the population decline study

Days of fallow	Number of observations	Days of fallow	Number of observations
47	18	134	17
57	14	192	10
74	28	194	17
87	10	199	2
92	25	219	3
104	72	229	4
122	16	249	9

observations for that fallow period (Ferris, 1984). These means were regressed on the fallow lengths using the negative exponential model. Regression analysis was performed using the Excel software program (Microsoft Corporation, Redmond, WA).

Results

Final population densities of *B. longicaudatus* (Y) increased on cotton when Pi densities (x) were < 100 nematodes/130 cm^3 of soil but declined at Pi densities > 130 nematodes/130 cm^3 of soil (Fig. 4-1). Therefore the quadratic model $Y = -0.0085x^2 + 1.91x + 31.8$ ($R^2 = 0.52$, $P > 0.01$) was used for the nontransformed data (Fig. 4-1). The carrying capacity, estimated by calculation from the first derivative of the quadratic regression model, was 139 nematodes/130 cm^3 of soil (Fig. 4-1). For ln (x +1) transformed data the linear model $Y = 0.41x + 2.82$ ($r^2 = 0.38$, $P < 0.01$) was used (Fig. 4-2). The regression line was above the maintenance line, where Pf = Pi, until it intersected at the ln (Pi+1) density of 4.8 (115 nematodes/130 cm^3 of soil). Above this Pi density, the damage caused by *B. longicaudatus* to cotton was so severe that food supply restrictions limited nematode reproduction.

The population decline model is the negative exponential regression $Y = 1.37e^{-0.0131x}$ ($r^2 = 0.90$, $P < 0.0001$) (Fig. 4-3). Based on this model, *B. longicaudatus* population densities decrease more rapidly during the initial days of a fallow period, and less rapidly thereafter. From this data we can predict that the population density will decrease by 30% after 50 days of clean fallow, 64% after 100 days, 81% after 150 days, 90% after 200 days, and 95% after 250 days.

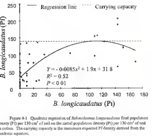


Figure 4-1. Quadratic regression of *Belonolaimus longicaudatus* final population density (Pf) per 130 cm^3 of soil on the initial population density (Pi) per 130 cm^3 of soil on cotton. The carrying capacity is the maximum expected Pf density derived from the quadratic equation.

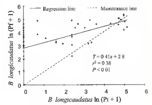


Figure 4-2 Linear regression of ln $(x + 1)$ transformed final population density (Pf) per 130 cm^3 of soil on ln $(x + 1)$ transformed initial population density (Pi) per 130 cm^3 of soil for *Belonolaimus longicaudatus* on cotton. The maintenance line is where ln (Pf + 1) = ln (Pi + 1). A regression line above the maintenance line indicates that the population density increases.

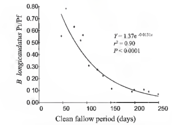


Figure 4-3 Population decline model for *Belonolaimus longicaudatus* during clean fallow. The relationship is described by the negative exponential regression of the proportion of the original population remaining after fallow regressed on the length of fallow.

Discussion

The linear damage function reported for sting nematode on cotton (Chapter 3) provides a sound method for calculating expected yield losses based on the number of *B. longicaudatus* in a soil sample. The model can be used to make informed management decisions based on current nematicide application costs and expected crop value. The damage function for sting nematode on cotton is described by the linear model $Y = -18.36x + 2848$ ($r^2 = 0.77$, $P < 0.0001$) (Chapter 3). From this model, we can predict that each sting nematode in a soil sample may result in a decrease of 18.4 kg/ha in seed cotton yield. With average cotton prices of $1.62/kg in 1997 (Anonymous, 1999) each sting nematode detected in a soil sample would translate to a loss of $30.84/ha. A nematicide treatment of 1,3-D at the recommended rate of 56 liters/ha is estimated to cost ca. $157/ha, whereas an aldicarb treatment at the recommended rate of 1.68 kg a.i./ha is estimated to cost ca. $74 kg/ha (Smith and Taylor, 1999). With these estimates, the economic threshold for management of *B. longicaudatus* on cotton would be 5 nematodes/130 cm^3 of soil for 1,3-D, and 2 nematodes/130 cm^3 of soil for aldicarb.

High densities of *B. longicaudatus* at planting resulted in death of most cotton seedlings. A very poor stand was observed with densities > 100 *B. longicaudatus*/130 cm^3 of soil. When large numbers of seedlings die and an alternative food source is lacking, nematode population densities decline. At low P_i densities, cotton plant damage was not severe enough to restrict reproduction of *B. longicaudatus*. However, as P_i densities increased, the amount of plant damage also increased until reproduction was reduced, explaining the quadratic relationship between P_i and P_f.

The population increase model indicates that when cotton is grown in soil infested with *B. longicaudatus* the nematode densities in the first season are expected to reach a maximum of ca. 140 nematodes/130 cm^3 of soil. 'DPL 5415' cotton is a 150-day crop, so the expected fallow interval between cotton crops in monocropping is 200 days. From the population decline model it is projected that sting nematode densities would decrease by 92% during this interval. If clean fallow or a non-host cover crop is used between crops, the maximum P_i for the following season is expected to be 11 nematodes/130 cm^3 of soil. This would be near the economic threshold of approximately 5 nematodes/130 cm^3 of soil, as calculated above for nematicide use. From the population increase model, the population density at the end of the second season is expected to be < 50 nematodes/130 cm^3 of soil. During the second year, population densities following fallow are expected to decline to ≤ 4 nematodes/130 cm^3 of soil, which is near or below the economic threshold. Thus, continuous monocropping of cotton in soil infested by *B. longicaudatus* could be sustainable with the absence of a host between subsequent cotton crops.

This study shows the importance of maintaining a non-host winter cover crop between sequential cotton crops grown in soil infested with *B. longicaudatus*. These practices should eliminate the need for chemical management by the second or third year. When potato, a host crop, was grown during the period between cotton crops, the P_i densities of *B. longicaudatus* for the following cotton crop were always > 100 nematodes/130 cm^3 of soil. Further research is needed to identify winter cover crops that are non-hosts or poor hosts for *B. longicaudatus*. While several studies have been

conducted on summer cover crops (McSorley and Dickson, 1995; Reddy et al., 1986, Rhoades, 1983) there has been only one study on the effects of winter cover crops on sting nematode (McSorley and Dickson, 1989b). It should be noted that rye (*Secale cereale* L.), a common winter cover crop used in cotton production in Florida, was found to maintain or increase densities of *B. longicaudatus* (McSorley and Dickson, 1989b).

Care should be taken in applying these models to other cotton varieties and locations. These models were developed using a single cotton variety ('DPL 5415') and a single nematode isolate from Hastings, Florida. *Belonolaimus longicaudatus* Pf densities were < 30 nematodes/100 cm^3 of soil following 'Georgia King' cotton in Tifton, Georgia (Johnson et al., 1998). In another test at the same location, Pf densities were > 150 *B. longicaudatus*/100 cm^3 of soil following 'Coker 413-67' cotton (Johnson, 1970). Data from a single year suggest that 'DPL 50' may be a better host for the *B. longicaudatus* isolate from Hastings, Florida than is 'DPL 5415' (W.T. Crow, unpubl. data).

CHAPTER 5
DAMAGE FUNCTION AND ECONOMIC THRESHOLD FOR *BELONOLAIMUS LONGICAUDATUS* ON POTATO

Introduction

Belonolaimus longicaudatus Rau (sting nematode) is a destructive pathogen of many economically important plants (Perry and Rhoades, 1982, Smart and Nguyen, 1991). Sting nematode is limited to soils with < 80% sand content (Robbins and Barker, 1974) and is found primarily in the sandy coastal plains of the southeastern United States. Currently, northeastern Florida has the only important potato (*Solanum tuberosum* L.) production area where sting nematode is commonly found (Brodie, 1998). The nematode is present in most of the potato fields in this region (Nguyen and Smart, 1975, Weingartner et al., 1977).

All commercial potato fields in northeast Florida are treated with nematicides each year for management of *B. longicaudatus*, *Meloidogyne incognita*, *Trichodorus spp.*, and *Paratrichodorus spp.*, the latter two nematodes transmit the tobacco rattle virus (Weingartner et al., 1993, Weingartner and Shumaker, 1983). The use of nematicides has been associated with significant yield increases in the region, primarily because of management of *B. longicaudatus* (Weingartner et al., 1993, Weingartner and Shumaker, 1983).

Potato has been reported as an excellent host for *B. longicaudatus* in greenhouse tests (Robbins and Barker, 1973) and has been associated with yield losses of potato in the field (Weingartner et al., 1977, 1978). However, damage functions for *B. longicaudatus* and economic threshold densities for management on potato have never been quantified. Knowledge of the economic threshold population density, the point at which the expected decline in crop value is equal to management cost (Ferris, 1978), would be useful in avoiding unnecessary nematode applications. If economic threshold population densities were known, growers could apply chemicals based on soil test results rather than prophylactically. Our objective was to derive the damage function for *B. longicaudatus* and use it to calculate the economic threshold density.

Materials and Methods

A 2-year field study was carried out during 1997 and 1998 for quantifying yield losses in 'Atlantic' potato due to root damage caused by *B. longicaudatus*. This study was conducted at the University of Florida Agricultural Research and Education Center, Yelvington Farm near Hastings, Florida. The site selected was naturally infested with *B. longicaudatus*, *Criconemella* sp., *Dolichodorus heterocephalus*, *Hemicycliophora* sp., *Meloidogyne incognita* race 1, *Paratrichodorus minor*, *Pratylenchus brachyurus*, *P. zeae*, and *Tylenchorhynchus* sp. The soil is an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf) composed of 95% sand, 2% silt, 3% clay; < 1% organic matter; pH 6.5 to 7.0.

Initial nematode populations (P_i) were modified by prior cropping system and soil fumigation to obtain yield data covering a wide range of nematode population

densities A split-plot design was used with the cropping system as the whole plot and nematicide treatment as the subplot. Cropping treatments were: (i) winter-spring 'Atlantic' potato followed by a cover crop of sorghum-sudangrass hybrid (*Sorghum bicolor* (L.) Moench × *S. arundinaceum* (Desv.) Stapf var. *sudanense* (Stapf) Hitchc.), both hosts for *B. longicaudatus* (McSorley and Dickson, 1995, Robbins and Barker, 1973), (ii) winter-spring potato in 1 year rotation with summer cotton (*Gossypium hirsutum* L.), a host for *B. longicaudatus* (Graham and Holdeman, 1953), (iii) winter-spring potato double-cropped with summer cotton, and (iv) winter-spring potato followed by a summer cover crop of velvetbean (*Mucuna pruriens* (Wallich ex Wight) Baker ex Burck, syn. *M. deeringiana*), a non-host for *B. longicaudatus* (McSorley and Dickson, 1995). Nematicide treatments were an untreated control, and a treatment in which plots were fumigated with 1,3-dichloropropene (1,3-D) at the rate of 56 liters/ha (570 ml/100 m row) with a single chisel per row. Five replications of each treatment combination were used.

The experiment was carried out on ridged rows with 102 cm spacing between rows, and the plot area was watered by seepage irrigation (Campbell et al., 1978, Rogers et al., 1975). Field plots were four rows wide and 9 m long. Two clean fallow rows were maintained between adjacent plots, and 3 m of clean fallow were maintained between plots in the same rows. All nematode and yield data were collected from the inner two rows of each plot.

Potato seed pieces were planted 10 February 1997 and 27 February 1998, and harvest dates were 5 May 1997 and 8 June 1998. Forty-five potato seed pieces were

hand placed in each row at 20 cm spacing. Potato tubers were harvested with a single-row mechanical harvester. Following harvest, tubers were graded by size using a mechanical grader and weighed. Only tubers ≥ 3.81 cm-diam. were included in the analysis.

Nematode samples were collected 1 day before planting (Pi). Twelve 2.5-cm-diam. cores were taken 20 cm deep from each plot, and composited. Nematodes were extracted from a 130 cm^3 subsample using a modification of the centrifugal-flotation method (Jenkins, 1964) described previously (Chapter 3). Following extraction, nematodes were counted using an inverted light microscope at ×32 magnification.

Multiple-regression analysis was used to compare the relative degrees of association of the different plant-parasitic nematodes in the system with potato yields. Potato yields were regressed on Pi density of all genera of plant-parasitic nematodes using stepwise multiple regression (Ott, 1993). Multiple-regression analysis was performed using the SAS software program (SAS Institute, Cary, NC). Nematodes contributing the most to the R^2 of the stepwise regression model were considered to have the greatest effect on yield (McSorley and Waddill, 1982). Linear regression of yield on Pi density (Ott, 1993) was used to generate damage functions for *B. longicaudatus* on potato. Linear regression was performed using the Excel software program (Microsoft Corporation, Redmond, WA). Damage functions derived for each year were tested for heterogeneity of slope using the SAS software program (SAS Institute, Cary, NC), to detect variability between the 2 years (Freund and Littell, 1981).

Following derivation of damage functions, published economic data were used to establish economic thresholds for nematicide application. Published market values (Anonymous, 1999) for potato during the harvest months of 1997 and 1998 were multiplied by the average slope of the damage function derived from the data for the 2 years. This value was used as an estimate of the dollar value of yield reduction associated with each *B. longicaudatus* detected in a soil sample. The cost of nematicide treatment was then divided by the estimated loss per nematode to calculate the economic threshold density.

Results

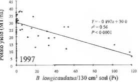
As determined by the stepwise multiple-regression analysis, *B. longicaudatus* was the only plant-parasitic nematode with a significant relationship to potato yield in both years (Table 5-1). The only other nematode that contributed significantly to the model in either year was *D. heterocephalus* in 1997. The relationship between yield (Y) and Pi of *B. longicaudatus* per 130 cm^3 of soil (x) was described by the linear model $Y = -0.197x + 30.0$ for 1997, and $Y = -0.200x + 35.8$ for 1998 (Fig. 5-1). These slopes were not heterogeneous ($P = 0.973$); only the Y intercepts were different. Based on the average slope of the 2 years (- 0.199x), each nematode detected in a soil sample was associated with a 199 kg/ha loss in potato tuber yield.

Local potato prices during the study period ranged from $0.23/kg to $0.45/kg (Anonymous, 1999) (Table 5-2). When the slope of the damage function was multiplied by potato price, the dollar loss per nematode detected ranged from $46 to $89 per hectare. The cost of nematicide application was $159/ha for aldicarb at 3.36 kg a.i./ha, and

Table 5-1. Results of stepwise multiple-regression analysis of potato yield on initial population densities of all plant-parasitic nematodes present at the field site in 1997 and 1998

	Nematodes/130 cm³ of soil			
	1997		1998	
Nematode	R^2	Prob > F	R^2	Prob > F
Belonolaimus longicaudatus	0.56	0.0001	0.20	0.0035
Meloidogyne incognita	NS[a]	NS	NS	NS
Paratrichodorus minor	NS	NS	NS	NS
Pratylenchus spp.	NS	NS	NS	NS
Tylenchorhynchus sp.	NS	NS	NS	NS
Criconemella sp.	NS	NS	NS	NS
Dolichodorus heterocephalus	0.05	0.03	NS	NS
Hemicycliophora sp.	NS	NS	NS	NS

[a]NS = Regression was not significant at $P \leq 0.15$



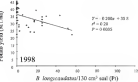


Figure 5-1. Damage functions for *Belonolaimus longicaudatus* on potato in 1997 and 1998. The damage functions are derived by the linear regression of potato tuber yield (MT/ha) on initial population density (Pi) of *B. longicaudatus*.

Table 5-2 Economic thresholds for *Belonolaimus longicaudatus* on potato

Date	Potato price ($/kg)	Monetary loss ($/nematode)	Threshold for aldicarb	Threshold for 1,3-D
April 1997	0.29	57[a]	3[b]	3
May 1997	0.24	48	3	3
June 1997	0.25	50	3	3
April 1998	0.45	89	2	2
May 1998	0.25	50	3	3
June 1998	0.23	46	3	3

[a]The potato price was multiplied by slope of the linear damage function (- 199 kg/ha yield reduction per nematode detected per 130 cm^3 of soil) to obtain the monetary loss per hectare associated with each nematode detected in a soil sample

[b]The cost of nematicide application per hectare ($159/ha for aldicarb, $149/ha for 1,3-dichloropropene) was divided by the monetary loss per nematode to derive the economic threshold for management of *B. longicaudatus* with each nematicide.

\$149/ha for 1,3-D at 56 liters/ha 1,3-D (Smith and Taylor, 1999). These values were divided by the dollar losses per nematode to determine the economic threshold for *B. longicaudatus*. Economic threshold densities were two to three *B. longicaudatus*/130 cm^3 of soil (Table 5-2).

Discussion

The typical Seinhorst model for plant damage caused by plant-parasitic nematodes has a downward sloping sigmoidal shape (Seinhorst, 1965). According to the Seinhorst model there is a tolerance population density, or tolerance limit. At Pi densities below the tolerance limit damage is not observed (Seinhorst, 1965). Seinhorst (1965) also introduced the concept of minimum yield. The minimum yield is that at which no further reductions occur regardless of increases in nematode Pi density. Tolerance limits for a pathogenic nematode such as *B. longicaudatus* may be below or near the detection level. Additionally, high Pi densities result in such severe yield losses that minimum yield is near zero. Therefore, a linear model may be as valid in these circumstances as the typical Seinhorst (1965) model and has been used previously to describe damage functions for *Belonolaimus* sp. on other crops (McSorley and Dickson, 1989a; Todd, 1989).

From these data, which were generated by intensive sampling of small plots, it is determined that the economic threshold for *B. longicaudatus* on potato is near the detection threshold. Sampling error in small plots is less than in large commercial fields because as the size of the sampled area increases, the sampling error also increases (McSorley and Parrado, 1982). Therefore, the usefulness of the economic threshold in a typical grower's field may be adversely affected because of the large size and sampling

error. Any detectable Pi density of *B. longicaudatus* in commercial fields is likely to exceed the economic threshold for potato, and treatment may be recommended at the detection level.

CHAPTER 6
THE PATHOGENICITY OF *BELONOLAIMUS LONGICAUDATUS* ON POTATO

Introduction

Northeast Florida is the only major potato (*Solanum tuberosum* L.) producing region in the world reporting damage to potato by *Belonolaimus longicaudatus* Rau (Brodie, 1998). This situation is likely due to northeast Florida having environmental conditions favorable for the development of *B. longicaudatus*. Optimum reproduction of *B. longicaudatus* is limited to soil with > 80% sand content, and < 10% clay content (Robbins and Barker, 1974). The agricultural soils in northeast Florida are mostly in this range.

Belonolaimus longicaudatus is considered an important pathogen of potato in northeast Florida because of its statistical correlation with heavy crop losses (Weingartner and Shumaker, 1983, Weingartner et al., 1977, Weingartner et al., 1978, Weingartner et al., 1993). Although potato was shown to be a host for *B. longicaudatus* (Robbins and Barker, 1973), Koch's Postulates have never been adequately applied to determining the nematode's pathogenicity on potato.

Pathogenicity of an organism is considered proven when Koch's Postulates have been fulfilled. Koch's Postulates state that the pathogen must (i) be found associated with all diseased plants, (ii) be isolated and grown in pure culture on nutrient media or a host plant, (iii) when inoculated on healthy plants it must produce the same disease as on

the original plants, and (*iv*) be reisolated from the inoculated plants and be identical to the organism grown in culture (Agrios, 1997). The objective of this study was to apply Koch's Postulates to verify that *B. longicaudatus* is a pathogen of potato.

Materials and Methods

Two trials were performed in the greenhouse to verify the pathogenicity of *B. longicaudatus* on potato. General procedures for each experiment were similar except that the first trial was conducted for 73 days and the second for 83 days. An isolate of *B. longicaudatus* was collected from a potato field at the University of Florida Agricultural Research and Education Center, Yelvington Farm near Hastings, Florida and reared on bermudagrass (*Cynodon dactylon*) in the greenhouse. Mixed life stages of *B. longicaudatus* from the greenhouse population were extracted from soil using a modified Baermann method (McSorley and Frederick, 1991) and subsequently used to inoculate potato plants.

The soil used for this study was composed of 95% sand, 2% silt, 3% clay; < 1% organic matter, and was collected from the same site as the nematode isolate. This soil was measured into 25-cm-diam. clay pots, each pot received 5,700 cm^3 of soil. The pots and soil were then autoclaved at 250 °C and 0.131 kPa pressure for 1 hour. Inoculum consisting of nematodes suspended in water was pipetted into five holes 1 cm wide and 2 cm-deep in the soil. Inoculation rates were 0, 30, 60, and 150 *B. longicaudatus*/130 cm^3 of soil. A single 'Atlantic' potato minituber was planted 5 cm deep in the center of each pot. Pots were then placed in a completely randomized design on a bench in the greenhouse.

Potato plants were fertilized 2, 5, and 7 weeks after planting with 150 mg N, 132 mg P, 125 mg K, and micronutrients dissolved in 1 liter water. The first trial was conducted from 26 December 1997 to 10 March 1998. The second trial was conducted from 26 May 1998 to 14 August 1998. Greenhouse temperatures were maintained between 18 °C and 27 °C during the first trial, and fluctuated between a low of 24 °C and a high of 37 °C during the second trial. Light for both trials was from ambient sunlight.

Soil was gently removed from around the potato roots and tubers with water at the end of each trial, and tubers were collected and weighed. All tubers of different sizes and maturity stages were collected, however only tubers with weights > 20 g were included in statistical analyses.

Root lengths, and surface areas for different root diameter ranges were quantified using an HP Scanjet 2cx desktop scanner (Hewlett Packard, Boise, ID) and GSRoot (Louisiana State University, Baton Rouge, LA) root-analyzing software. The entire root systems were too large to be accommodated in a single scan. Therefore, the root systems were divided into 5 to 18 subsamples based on the size of the root system. Each subsample was placed into a plastic cup with 150 ml water and stained with three drops of 1% methylene blue. Following staining, root systems were scanned to create a bitmap image of the root system (Kaspar and Ewing, 1997; Pan and Bolton, 1991). The images were then imported for analysis into the software program. This program allows analysis of roots of specified diameter ranges, and calculates root surface area and length measurements for all roots in the sample of each specified range. Root diameter ranges

used in this study were < 0.2-mm, 0.2 to 0.5-mm, 0.5 to 1.0-mm, 1.0 to 2.0-mm, and ≥ 2.0-mm.

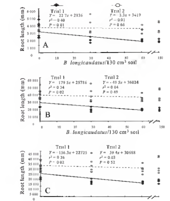
Tubers in the second trial were rated for shape and brightness on a scale of 1 to 5. For shape, a perfectly round tuber would receive a rating of 5, while a grossly misshapen one would receive a rating of 1. For brightness, a clear, white tuber with no blemishes would receive a rating of 5, whereas darkened tuber with sunken lenticels would receive a rating of 1.

Tuber yield and root length data were subjected to regression analysis (Ott, 1993). Tuber yields and root length measurements were regressed on inoculation density of *B. longicaudatus*. Root length measurements were analyzed separately for each diameter range. Regression analysis was performed using the Excel software program (Microsoft Excel, Redmond, WA). Visual ratings were subjected to analysis using the general linear model procedure (Ott, 1993) and mean comparisons among the inoculation levels were made with Duncan's multiple-range test using the SAS software program (SAS Institute, Cary, NC).

Results

Results were inconsistent between trials; therefore, the data from each trial are shown separately. In the first trial the regression of root length on inoculation density of *B. longicaudatus* was significant for all root diameter ranges < 1.00 mm ($P < 0.05$) (Fig. 6-1). In the second trial the regressions were not significant for any diameter range studied ($P \leq 0.05$) (Fig. 6-1). No changes in root length between inoculation densities of

Fig. 6-1. Regression of root lengths with increasing diameter ranges on inoculation density of *Belonolaimus longicaudatus*. Root diameter ranges are < 0.2 mm (A), 0.2 to 0.5 mm (B), and 0.5 to 1.0 mm (C). Because of heterogeneity of slope, the regression lines for each trial are shown separately.



Trial 1
Y = 22.7x + 2836
r² = 0.40
P = 0.01
Trial 2
Y = 3.3x + 3419
r² = 0.01
P = 0.66
A
Root length (mm)
B. longicaudatus/130 cm³ soil
Trial 1
Y = 179.5x + 25786
r² = 0.34
P = 0.02
Trial 2
Y = -49.5x + 36024
r² = 0.04
P = 0.49
B
Root length (mm)
B. longicaudatus/130 cm³ soil
Trial 1
Y = -156.3x + 22725
r² = 0.36
P = 0.02
Trial 2
Y = 39.4x + 30688
r² = 0.03
P = 0.52
C
Root length (mm)
B. longicaudatus/130 cm³ soil

60 and 150 *B. longicaudatus*/130 cm^3 of soil were observed at any diameter range in either trial ($P < 0.05$). Therefore, the relationship of root length to inoculation density is described by a linear regression equation between densities of 0 to 60 *B. longicaudatus*/130 cm^3 of soil for each diameter range.

Yields fluctuated greatly within the same inoculation rate for the lower rates in the first trial (Fig. 6-2). As a result, the regression of tuber yields on inoculation density of *B. longicaudatus* was not significant for this trial ($P = 0.11$). The regression was significant in the second trial, in which less variation occurred ($P = 0.007$) (Fig. 6-2). Inoculation with *B. longicaudatus* in the second trial resulted in decreases in tuber shape and brightness ratings (Fig. 6-3). These qualities were not assessed in trial one.

Discussion

Although *B. longicaudatus* has been associated with yield reduction and plant damage in the field (Chapter 5, Weingartner et al., 1977, Weingartner et al., 1978), its pathogenicity was not demonstrated conclusively by these experiments because of the inconsistency between the two trials. The inconsistency may be explained by differences in temperature and light conditions while the trials were conducted. The first trial was conducted during the winter, and the second during the summer. During the first trial temperatures within the greenhouse were kept relatively constant with the use of a thermostat-controlled heater. Outside temperatures during the second trial reached 41 °C. The greenhouse was equipped only with a fan for cooling. Therefore, temperatures within the greenhouse fluctuated greatly and were often above optimum for both potato and *B. longicaudatus* during the day. Throughout the second trial, day length was

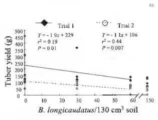
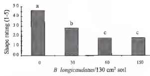


Figure 6-2. Regression of potato tuber weights > 20 g on inoculation density of *Belonolaimus longicaudatus* per 130 cm^3 of soil from each of two trials. Regression lines from the trials are shown separately. Because there were no significant differences between inoculation densities of 60 and 150 *B. longicaudatus*/130 cm^3 of soil ($P < 0.05$), only inoculation densities of 0 to 60 *B. longicaudatus*/130 cm^3 of soil are used for regression analysis.



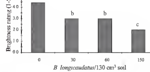


Figure 6-3 Effect of inoculation density of *Belonolaimus longicaudatus* per 130 cm^3 of soil on tuber shape and brightness Tubers from each pot were given a visual rating for each quality on a scale of 1 to 5 with 5 being the best rating. The means among inoculation rates were separated according to Duncan's multiple-range test ($P < 0.05$)

longer and the sunlight more direct than during the first. Both temperature and light may have contributed to the variation in results.

Because these trials were inconsistent, further research is needed. A similar study using the same techniques to quantify the effects of *B. longicaudatus* on cotton was successful (Chapter 3). For the cotton study smaller pots were used, and the experiment was conducted in controlled environmental chambers in which temperatures and lighting were closely regulated. The cotton also was only grown for 45 days. Perhaps if additional potato studies were performed using controlled environmental chambers, and a shorter study period, the results would be more consistent.

CHAPTER 7
EVALUATION OF SORGHUM-SUDANGRASS AND VELVETBEAN COVER CROPS BASED ON THEIR EFFECTS ON *BELONOLAIMUS LONGICAUDATUS*, OTHER PLANT-PARASITIC NEMATODES, AND POTATO YIELDS

Introduction

Potato (*Solanum tuberosum* L.) in Florida is grown during the winter spring months, and is usually followed by a cover crop during the summer months. The cover crop most commonly grown in the northeast Florida potato production area during the past 20 years has been a sorghum sudangrass hybrid (*Sorghum bicolor* (L.) Moench × *S. arundinaceum* (Desv.) Stapf var. *sudanense* (Stapf) Hitchc.) (Weingartner et al., 1993). This cover crop is incorporated with the soil after maturity and is valued primarily for its biomass production. Cover crop residues serve to maintain the integrity of the potato rows by providing protection from soil erosion until the potato canopy covers the rows (Myhre, 1957). Sorghum-sudangrass also serves to restrict weed growth during the summer and to prevent soil erosion from frequent heavy rainfall. Summer weeds increase weed management problems in the subsequent potato crop, and may serve as alternate hosts for soilborne pathogens such as *Ralstonia solanacearum* (syn. *Pseudomonas solanacearum*) and *Meloidogyne incognita* (Weingartner, unpubl. data).

Sorghum-sudangrass may have some undesirable qualities, such as being an alternate host for *Belonolaimus longicaudatus*, *Paratrichodorus minor*, and other plant-parasitic nematodes (Weingartner et al., 1993). Nearly 100% of the commercial potato

fields in northeast Florida are treated each year with chemical nematicides to manage these nematodes and associated disease complexes (Weingartner and Shumaker 1983 Weingartner and Shumaker, 1990b) These nematicide applications are a major expense for potato growers Therefore, an alternative cover crop generating equivalent biomass and weed suppression, yet being a non-host for plant-parasitic nematodes, would be of great benefit to potato growers

Velvetbean (*Mucuna pruriens* (Walbch ex Wight) Baker ex Burck, syn *M deeringiana*) is a nitrogen-fixing tropical legume with a long history in Florida. From 1890 to 1930 it was commonly grown as a cover crop to add nitrogen to soil, and for animal feed (Clute, 1896; Miller, 1902) However, velvetbean fell out of common usage in Florida by the 1930s (Newell, 1930) Recently this crop has received renewed interest in the southeastern United States for suppression of plant-parasitic nematodes and other soilborne pathogens (McSorley et al., 1994a,b, Reddy et al, 1986, Rodríguez-Kábana et al, 1992, Weaver et al , 1993)

The objectives of this research were to (i) study the effects of sorghum-sudangrass and velvetbean cover crops on population changes of plant-parasitic nematodes and potato yields in the northeast Florida potato production system, (ii) quantify the effects of sorghum-sudangrass on nematode diseases in potato production, and (iii) evaluate the suitability of velvetbean as an alternative summer cover crop

Materials and Methods

A 3-year field experiment was carried out at the University of Florida Agricultural Research and Education Center, Yelvington Farm near Hastings, Florida. This site was

naturally infested with *B. longicaudatus*, *P. minor*, *M. incognita* race 1, *Pratylenchus brachyurus*, *P. zeae*, *Tylenchorhynchus* sp., *Dolichodorus heterocephalus*, *Criconemella* sp., and *Hemicycliophora* sp. Soil at the research site is an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf) consisting of 95% sand, 2% silt, 3% clay; < 1% organic matter; pH 6.05 to 7.0. Bed construction and irrigation were consistent with those reported for potato grown in the area (Campbell et al., 1978; Rogers et al., 1975).

The experimental design was a split-plot with whole-plots being cover crop treatments and the subplots being nematicide treatments. 'Atlantic' potato was grown in the spring followed by summer cover crops of either sorghum-sudangrass or velvetbean. Two nematicide treatments applied to potato were aldicarb, and 1,3-dichloropropene (1,3-D). Both cropping treatments also included an untreated control.

Plot dimensions were 9 m long and four rows wide with a row spacing of 102 cm. Three meters of clean fallow were maintained between plots in the same rows. Two clean fallow rows were maintained between adjacent plots. Yield and nematode data were collected from the two inner rows of each plot, and the two outer rows were border rows.

Planting and harvest dates for potato and cover crops are listed in Table 2.2. Clean fallow was maintained during the time interval between the cover crops and potato crops. Potato crops were fertilized at planting with 1,120 kg/ha of 14-2-12 (N-P_2O_5-K_2O). Nutrient rates were 157 kg/ha N, 10 kg/ha P, 112 kg/ha K, 23 kg/ha Mg, 45 kg/ha S, and trace amounts of other micronutrients. Cover crops also were fertilized at planting

with the same mixture and rate as used for potato. The sorghum-sudangrass was side-dressed with an additional 56 kg/ha N 1 month after planting.

Aldicarb (15G) was applied at time of potato planting in a 25-cm-wide band at the rate of 3.4 kg a.i./ha (34 g/100 m of row). Aldicarb was banded directly over potato seed pieces and was incorporated lightly as the beds were closed. 1,3-D was injected 25 to 30 cm deep into soil 3 weeks before planting potato at 56 liters/ha (570 ml/100 m of row) with a single chisel per row.

Nematode samples were collected at planting (Pi), and at harvest (Pf). Because cover crops were planted immediately following potato harvest, the potato Pf samples also served as the cover crop Pi samples. The soil also was sampled in January of each year before applying 1,3-D. Each sample was composed of 12 2.5 cm-diam. × 20 cm deep cores taken from the two center rows of each plot. Nematodes were extracted from a 130 cm^3 subsample using a modification of the centrifugal-flotation method (Jenkins, 1964) reported previously (Chapter 3). Following extraction, all plant-parasitic nematodes were counted with the aid of an inverted light microscope at a magnification of ×32. Potato tubers were harvested with a single-row mechanical harvester, and mechanically sized into grade categories: "A" (> 4.76 cm-diam.) and "B" (3.81 ≤ 4.76 cm-diam.). Tuber weight per plot was recorded for each grade category.

Nematode and yield data were subjected to analysis of variance using the general linear model procedure for split-plot design (Ott, 1993). The block × whole-plot interaction was used as the error term for the whole-plots (cropping treatments). Means were compared by Duncan's multiple-range test (Ott, 1993). The contrast procedure (Ott,

1993) was used to compare potato yields between the two cover crop treatments receiving the same nematicide treatment. The above analyses were performed using the SAS software program (SAS Institute, Cary, NC)

To determine host status, initial (Pi) and final (Pf) population densities were transformed with ln (x + 1) before analysis and the ratio of Pf/Pi was determined. A crop was considered a host if the Pf/Pi ratio was greater than one. A single data set composed of the nematode count data for all 3 years was used to determine host status. Extrapolating below detection thresholds (Pi samples with no nematodes detected) is difficult, so only plots with a Pi density ≥ 1 nematode/130 cm^3 of soil were included in analysis for host status.

The population densities of *B. longicaudatus* in potato production systems with sorghum-sudangrass and velvetbean cover crops were compared. Treatment means from the untreated plots of the two cropping system at each sampling date were compared by analysis of variance (Ott, 1993). Analysis of variance was performed using the SAS software program (SAS Institute, Cary, NC).

Results

Nematodes

Sorghum-sudangrass was a good host for *B. longicaudatus*, *P. minor*, *Pratylenchus* spp., *Tylenchorhynchus* sp., and *Criconemella* sp. (Table 7-1). The average Pf density was 168 nematodes/130 cm^3 of soil (SD = 96) for *B. longicaudatus* and 38 nematodes/130 cm^3 of soil (SD = 27) for *P. minor*. Velvetbean was a poor or non-host for *B. longicaudatus*, but a good host for *P. minor*, *Pratylenchus* spp., and *Criconemella*

Table 7-1 Host status of cover crops for the nematodes present in the field site. The numbers represent the mean of the ln $(Pf + 1)$/ln $(Pi + 1)$ of each nematode from 1996 to 1998. Numbers > 1 indicate a host. Numbers < 1 indicate a non-host. A value near 1 indicates that the population was maintained on the crop.

	Cover crop	
Nematode	Sorghum-sudangrass	Velvetbean
Belonolaimus longicaudatus	1.8 a	0.7 b
Paratrichodorus minor	2.0 a	1.9 a
Meloidogyne incognita	0.7 a	1.0 a
Pratylenchus spp	2.6 a	1.5 b
Tylenchorhynchus sp	1.5 a	0.9 b
Criconemella sp.	1.9 a	1.3 b
Dolichodorus heterocephalus	1.0 a	0.3 b
Hemicycliophora sp	0.8 a	0.0 a

Cover crop treatment means compared across columns followed by common letters are not significantly different according to Duncan's multiple-range test ($P < 0.05$)

sp (Table 7-1). The average Pf was 7 nematodes/130 cm^3 of soil (SD = 8) and 34 nematodes/130 cm^3 of soil (SD = 33) for *B. longicaudatus* and *P. minor*, respectively.

Soil samples collected at the beginning of the potato season in January were used to evaluate the effects of cover crop treatments on nematodes in the following potato crop (Table 7-2). Population densities of *B. longicaudatus* were greater following a cover crop of sorghum-sudangrass each year. Population densities of *Pratylenchus* spp., and *Criconemella* sp. were greater following sorghum-sudangrass 2 of 3 years. Population densities of *P. minor*, *Tylenchorhynchus* sp., and *D. heterocephalus* were greater following sorghum-sudangrass in 1 of 3 years. Densities of *M. incognita* juveniles were greater following a cover crop of velvetbean in 1997. The cover crop grown the preceding summer had a greater effect on *B. longicaudatus* density in January than did nematicide application to the preceding potato crop. Differences among nematicide treatments within the same cover cropping treatment were generally not significant ($P <$ 0.05) and are not reported.

When velvetbean was used as a cover crop, population densities of *B. longicaudatus* were reduced in comparison with sorghum-sudangrass as a cover crop (Fig. 7-1). Population densities of *B. longicaudatus* were lower on both the velvetbean and potato following velvetbean. Significant differences were observed at all sampling dates following the first cover crop season ($P < 0.05$).

Potato Yield

No differences in total potato yield were observed between the two cover crop treatments (Table 7-3). Tuber size differences were observed only in 1998 when plots

Table 7.2. Nematode population densities in January, at the beginning of the potato season, as influenced by the summer cover crop treatments

	1997		1998		1999	
Nematode	S[a]	V	S	V	S	V
BL[b]	30 a	2 b	61 a	1 b	77 a	5 b
PM	7 a	6 a	13 a	11 a	30 a	9 b
MI	2 b	40 a	25 a	31 a	70 a	39 a
PS	14 a	3 b	17 a	21 a	51 a	6 b
TS	15 a	11 a	3 a	6 a	15 a	4 b
CS	52 a	11 b	34 a	35 a	85 a	16 b
DH	1 a	0 a	2 a	1 a	5 a	0 a
HS	3 a	0 a	1 a	1 a	0 a	0 a

Cover crop treatment means compared across columns, within the same year, followed by common letters are not significantly different according to Duncan's multiple-range test ($P < 0.05$).

[a]S = Sorghum-sudangrass. V = Velvetbean.

[b]BL = *Belonolaimus longicaudatus*. PM = *Paratrichodorus minor*. MI = *Meloidogyne incognita*. PS = *Pratylenchus* spp. TS = *Tylenchorhynchus* sp. CS = *Criconemella* sp. DH = *Dolichodorus heterocephalus*. HS = *Hemicycliophora* sp.

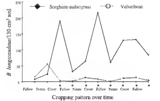


Figure 7 1 Effects of cover crops on population changes of *Belonolaimus longicaudatus* in potato production over 3 years without nematicide application. Data points are means of five replications. Asterisks indicate significant differences between the treatments at each sampling date

Table 7-3. Effects of cover crop treatments on potato yield (kg/ha) by class size. A = tubers > 4.76 cm-diam. B = tubers 3.81 ≤ 4.76 cm-diam. Total yield includes tubers culled for quality defects

	Summer cover crop treatment	
Size grade	Sorghum-sudangrass	Velvetbean
	1997	
U.S. size A	25,139 a	26,369 a
U.S. size B	1,331 a	1,466 a
Total yield	27,001 a	28,612 a
	1998	
U.S. size A	28,955 b	30,051 a
U.S. size B	1,745 a	1,200 b
Total yield	35,051 a	34,305 a

Cover crop treatment means for each size grade, compared across columns, followed by common letters are not significantly different according to Duncan's multiple-range test ($P < 0.05$)

with cover crops of sorghum-sudangrass yielded a greater weight of size B tubers and less weight of size A tubers than did plots with velvetbean cover crops. Contrasts of potato yield between the two cover crop treatments receiving the same nematicide treatment were not significantly different for any nematicide in either year (Fig. 7-2).

Discussion

Belonolaimus longicaudatus is the plant-parasitic nematode most strongly associated with yield reductions of potato in northeast Florida (Chapter 5, Weingartner et al., 1977, Weingartner et al., 1978). Population densities of *B. longicaudatus* were found to increase on sorghum-sudangrass. Because sting nematode has no long-term survival stage, clean fallow or a non-host crop is expected to lead to a decline in its population density. A population decline model for *B. longicaudatus* during clean fallow has been previously reported (Chapter 4). The fallow period between chopping down the sorghum-sudangrass and planting potato is around 100 days. Based on that population decline model, densities of *B. longicaudatus* are expected to decrease by 67% during this period. The Pf for *B. longicaudatus* on sorghum-sudangrass is expected, on average, to be 168. Therefore, the expected Pi for a subsequent potato crop is approximately 50 nematodes/130 cm³ of soil. This density is well above the economic threshold for nematicide application (Chapter 5). The use of sorghum-sudangrass as a summer cover crop for potato in northeast Florida is a major factor contributing to the need for annual nematicide applications. When velvetbean was substituted as a cover crop, densities of *B. longicaudatus* were substantially reduced.

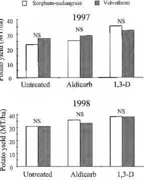


Figure 7-2 Potato yield contrasts between cover crop treatments for plots receiving the same nematicide treatments NS = Means within the nematicide treatment were not significantly different ($P < 0.05$)

Population densities of *M. incognita* were maintained on both sorghum-sudangrass and velvetbean cover crops. Sorghum-sudangrass is reported as a non-host for *M. incognita* (Johnson et al., 1977, McSorley et al., 1994a,b; McSorley and Dickson, 1995, McSorley and Gallaher, 1991), as is velvetbean (McSorley et al., 1994a,b McSorley and Dickson, 1995, Rodríguez-Kábana et al., 1992). A poor stand of velvetbean following potato often occurred because of seedling diseases. In addition, velvetbean was vulnerable to severe damage from lepidopteran pests that caused defoliation later in the season. Both factors contributed to weed development in the velvetbean plots. Weeds found in these plots with extensive galling from *M. incognita* were redweed (*Melochia corchorifolia*), pigweed (*Amaranthus hybridus*), and common purslane (*Portulaca oleracea*).

Sorghum-sudangrass was observed to be negatively affected by high population densities of *B. longicaudatus*. Sorghum-sudangrass growing in plots with high P_i densities of sting nematode had poor stands, and suffered stunting, particularly early in the season. Poor growth of sorghum-sudangrass allowed weed populations to increase in these plots that may serve as alternate hosts for *M. incognita*.

Potato yields following cover crops of velvetbean were comparable to those following the conventional sorghum-sudangrass. Individual yield comparisons between plots from the two cover crop treatments receiving the same nematicide treatment were never significantly different despite reductions in *B. longicaudatus*. Nematicide responses in velvetbean plots may be due to fumigation effects on *M. incognita* and other nematodes, or to effects on other soilborne pests or pathogens.

Sorghum-sudangrass may be beneficial to potato production, but also is a major contributing factor to nematode disease problems of potato in northeast Florida. Velvetbean cover crops reduced densities of *B. longicaudatus*, but did not increase potato yields in non-nematicide treated plots. For velvetbean to be a viable alternative to sorghum-sudangrass, the problems of poor stand and insect damage need to be addressed. The effects of sorghum-sudangrass and velvetbean on other aspects of potato production also need to be more thoroughly explored.

Nematode management is only one factor influencing the profitability of potato production in northeast Florida. This is the first published report quantifying the effects of sorghum-sudangrass and velvetbean cover crops on nematodes in this potato production region. The effects of cover crops on additional components of this agriculture system, such as other pests and pathogens, fertility, soil management, and erosion control have never been documented. In order for growers to make educated decisions regarding the use of cover crops, research on these factors must be continued. Then the benefits of each cover crop can be weighed against its liabilities, and proper management decisions made.

CHAPTER 8
EVALUATION OF POTATO-COTTON CROPPING SYSTEMS BASED ON THEIR EFFECTS ON *BELONOLAIMUS LONGICAUDATUS* OTHER PLANT-PARASITIC NEMATODES AND CROP YIELDS

Introduction

The number of hectares in Florida planted to cotton (*Gossypium hirsutum* L.) increased during the 1990s (Anonymous, 1999) expanding into some regions where cotton was not traditionally grown. One such region is northeast Florida where potato (*Solanum tuberosum* L.) has been produced for the last 100 years (Weingartner et al., 1993). *Belonolaimus longicaudatus* Rau (sting nematode) is well adapted to the northeast Florida area, and is commonly found in agricultural fields (Nguyen and Smart, 1975, Weingartner et al., 1993). Both cotton (Graham and Holdeman, 1953) and potato (Weingartner et al., 1977 Weingartner et al., 1978) are reported as being severely affected by *B. longicaudatus*.

Besides *B. longicaudatus* other nematodes considered important to potato production in the region are root knot nematodes (*Meloidogyne incognita*), and the stubby root nematodes (*Paratrichodorus minor* and *Trichodorus* spp.); the latter transmit the tobacco rattle virus. Other plant-parasitic nematodes commonly identified from growers fields in the area are *Dolichodorus* spp., *Criconemella* spp., *Helicotylenchus* spp., *Hemicycliophora* spp., *Hoplolaimus* spp., *Pratylenchus* spp., and *Tylenchorhynchus* spp. All of the commercial potato fields in northeast Florida are treated with chemical

nematodes for management of plant-parasitic nematodes and associated disease complexes (Weingartner and Shumaker, 1983).

Crop rotation has been shown to affect population densities of plant-parasitic nematodes greatly (Noe, 1998, Rodriguez-Kábana and Canullo, 1992). These effects may serve to reduce or exacerbate nematode problems depending on the crops and nematode species present in the system. Cotton and potato are not commonly grown in a crop production sequence, so it was not known how rotation or double cropping of these two crops would affect population densities of plant-parasitic nematodes in the system. The objectives of this study were to evaluate the viability of different potato and cotton cropping sequences based on population densities of plant-parasitic nematodes and crop yields

Materials and Methods

A field study was carried out in 1996 to 1998 at the University of Florida Agricultural Research and Education Center, Yelvington Farm near Hastings, Florida (Chapter 2). This site is located in a potato production region and has been used primarily for potato research during the past 40 years. Soil at the site is an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf) consisting of 95% sand, 2% silt, 3% clay; < 1% organic matter; pH 6.5 to 7.0. The site was naturally infested by *B longicaudatus*, *Criconemella* sp., *Dolichodorus heterocephalus*, *Hemicycliophora* sp., *M incognita* race 1, *P minor*, *Pratylenchus brachyurus*, *P zeae*, and *Tylenchorhynchus* sp. Bed construction and irrigation were consistent with standard potato production practices for the area (Campbell et al., 1978, Rogers et al., 1975).

The experimental design was a split-plot, with cropping systems as the whole-plots and nematicide treatments as the subplots. The field design used included five beds with each bed being a block. Five cropping treatments, and three nematicide treatments were tested. Plots were 9 m long, and 4 m wide with 102 cm between rows. Three meters of clean fallow were maintained as an alley between plots in the same rows. Two bare fallow rows were maintained between plots in adjacent rows. All data were collected from the center two rows of each plot. All statistical analysis was performed using the SAS software program (SAS Institute, Cary, NC).

Cropping system treatments were: (i) winter-spring potato followed by a cover crop of sorghum-sudangrass hybrid (*Sorghum bicolor* (L.) Moench × *S. arundinaceum* (Desv.) Stapf var. *sudanense* (Stapf) Hitchc.), representing the standard cropping system for potato in the region (Weingartner et al., 1993), (ii) monocropped cotton grown during the summer, (iii) winter-spring potato double-cropped with summer cotton, (iv) cotton and potato in a 1-year rotation, and (v) 2 years of summer cotton followed by winter-spring potato and summer sorghum-sudangrass in the third year. Nematicide treatments were aldicarb, 1,3-dichloropropene (1,3-D), and untreated.

Aldicarb was applied in a 25-cm-wide band at the rate of 3.4 kg a.i./ha (34 g/100 m of row) directly over potato seed pieces and was incorporated lightly as the beds were closed. Prior to planting cotton, the rows were flattened with a stalk chopper and aldicarb was applied in a 25-cm-wide band at the rate of 1.7 kg a.i./ha (17 g/100 m of row) on top of the flattened rows. The aldicarb was then incorporated with the soil as the rows were reshaped for planting. 1,3-D was injected into the soil at the rate of 5.6 liters/ha (570

ml/100 m of row) by a single chisel per row 25 to 30 cm deep 3 weeks before planting of either crop.

For the double-cropped treatments, nematicides were applied to both crops Untreated plots received no nematicide on either crop In plots where potato was treated with aldicarb, the cotton also was treated with aldicarb In plots where potato was fumigated with 1,3-D, the cotton was treated with aldicarb

Potato was planted in February to early March each year and harvested in May to early June (Chapter 2, Table 2-2) Forty-five 'Atlantic' potato seed pieces were planted in each row at 20 cm spacing between pieces Potato tubers were mechanically harvested with a single-row harvester, graded, and weighed. Analysis was limited to tubers ≥ 3 81cm-diam

All cotton, except the double-cropped cotton, was planted in late April in 1996 and harvested in mid-October (Chapter 2, Table 2-2) The double-cropped cotton was planted in early June, following the potato harvest, and harvested in early December (Chapter 2, Table 2-2) In 1997 and 1998 all the cotton was planted and harvested at the same time. Cotton was planted in late May, and harvested in early November in 1997, and planted in late June and harvested early in December in 1998 (Chapter 2, Table 2-2)

The cotton cultivar DPL 50 was used in 1996 Variety trials ongoing at the time showed that this variety was unsuited to local conditions (D Colvin, unpubl. data) Thereafter, in 1997 and 1998, the cultivar DPL 5415 was used Cotton seed was mechanically planted, and thinned to 15 cm spacing between plants following emergence.

Cotton was harvested with a single-row mechanical harvester, and weight of seed cotton yield was recorded.

Nematode data was collected by taking 12 2.5-cm-diam. cores from the two center rows of each plot. The 12 cores were composited to form a single sample. Nematodes were extracted from a 130 cm^3 subsample using a modification of the centrifugal flotation method (Jenkins, 1964) reported previously (Chapter 3). Following extraction, all genera of plant-parasitic nematodes were counted with an inverted light microscope at ×32 magnification.

The nematode samples that were collected in January of each year represented the initial population density (Pi) at the beginning of the potato season. Data from these nematode samples were used to evaluate the effects of cropping systems the previous year on the current potato crop. Nematode counts were subjected to analysis using the general linear model procedure for split plot design and the means were separated according to Duncan's multiple-range test (Ott, 1993). The block × whole-plot interaction was used as the error term for the whole-plot treatments.

Nematicide treatment means within the same cropping system treatment were subjected to analysis using the general linear model procedure, and the means were compared using Duncan's multiple-range test (Ott, 1993). Significant differences ($P <$ 0.05) were observed in only one instance; the *B. longicaudatus* population density mean was lower following the double-cropped treatment where potato was treated with 1,3-D and cotton was treated with aldicarb than following either of the other two nematicide

treatments in 1997. Therefore, only the whole-plot (cropping system) treatment means are reported.

Some cropping treatments were the same for the first 1 or 2 years of the study. For instance, the monocropped cotton treatment and two treatments with potato and cotton in rotation all had monocropped cotton during the first year. The monocropped cotton treatment, and potato following 2 years of cotton both had monocropped cotton during the first 2 years of the study. In these cases the identical treatments were analyzed as additional replications of one treatment.

The double-cropped treatments had nematicide applied to both the potato and cotton crops. Therefore, cotton yields could not be analyzed as a split-plot design, so cotton yields were analyzed as a completely randomized design. Each cropping treatment × nematicide treatment combination was analyzed as a separate treatment. The cotton yields were subjected to analyses using the general linear model procedure and the means were separated by Duncan's multiple-range test (Ott, 1993).

Results

Nematodes

Initial population densities of *B. longicaudatus* were highest following the double-cropped treatment in January 1997, but were not different from the monocropped potato followed by sorghum-sudangrass treatment in 1998, and in 1999 ($P < 0.05$) (Table 8-1). P_i densities of *B. longicaudatus* following monocropped cotton for 2 or 3 years were lower than following potato and sorghum-sudangrass. In 1999, the lowest P_i densities for

Table 8-1 Effect of cropping systems on population densities of plant-parasitic nematodes assayed in January each year

	Sampling date												
	January 1997			January 1998				January 1999					
Taxon	P[a]	C	D	P-P	C-C	D-D	C-P	P-P-P	C-C-C	D-D-D	C-P-C	C-C-P
BL[b]	30 b	28 b	108 a	61 a	36 b	68 a	51 ab	77 a	13 a	50 b	23 c	39 b
CS	52 a	11 b	7 b	34 a	31 a	10 a	41 a	85 a	4 b	1 b	22 b	21 b
DH	1 a	< 1 b	< 1 b	2 a	1 ab	0 b	< 1 b	5 a	0 b	0 b	0 b	< 1 b
HS	3 a	< 1 a	0 a	< 1 a	1 a	0 a	4 a	0 a	2 a	0 a	4 a	< 1 a
MI	2 a	< 1 b	3 a	25 a	1 c	13 b	< 1 b	70 a	1 b	47 a	1 b	10 b
PM	7 ab	5 b	11 a	13 a	15 a	17 a	18 a	30 a	37 a	14 b	40 a	12 b
PS	14 a	1 b	1 b	17 a	20 a	9 a	23 a	51 a	10 b	7 b	9 b	7 b
TS	15 a	3 b	3 b	3 a	6 a	5 a	10 a	15 a	< 1 b	< 1 b	1 b	2 b

Means compared across columns within the same year followed by common letters are not significantly different according to Duncan's multiple-range test ($P < 0.05$)

[a] P = potato followed by sorghum-sudangrass C = cotton D = potato and cotton double-cropped in the same year

[b] BL = *Belonolaimus longicaudatus* CS = *Criconemella* sp DH = *Dolichodorus heterocephalus* HS = *Hemicycliophora* sp MI = *Meloidogyne incognita* PM = *Paratrichodorus minor* PS = *Pratylenchus* spp TS = *Tylenchorhynchus* sp

B. longicaudatus were found following either monocropped cotton or cotton rotated with potato.

Population densities of *M. incognita* second-stage juveniles (J2) in soil were lower following either monocropped cotton or cotton and potato in rotation than after potato followed by sorghum-sudangrass in 1998 and 1999 ($P < 0.05$). Pi densities of both *Pratylenchus* spp., and *Criconemella* sp. were lower following all other cropping treatments in comparison with the potato followed by sorghum-sudangrass in 1997 and 1999 ($P < 0.05$). Other plant parasitic nematodes did not build to large Pi numbers following any of the treatments. While differences were detected in some cases, these were not considered meaningful because of the low numbers.

Yields

Potato yields were lower for double-cropped potato than potato followed by sorghum-sudangrass in 1997, but were not significantly different in 1998 ($P < 0.05$) (Table 8-2). Potato yields following 1 year of cotton in 1997 were equivalent to those following potato and sorghum-sudangrass, but were lower in 1998 ($P < 0.05$).

When cotton was double-cropped with potato, yields were lower than for monocropped cotton when no nematicides were used ($P < 0.05$) (Table 8-3). When nematicides were applied to cotton double-cropped with potato, yields were comparable to yields in monocropping. Rotation of cotton with potato and sorghum-sudangrass did not affect cotton yields in comparison with monocropped cotton.

Table 8.2. Effects of cropping system and nematicide treatments from the previous 1 or 2 years on potato yields (kg/ha)

1997				1998			
Whole-plot[a]		Subplot		Whole-plot		Subplot	
Treat	Yield	Treat	Yield	Treat	Yield	Treat	Yield
PS[b]	27,001 a	U[c]	22,006 b	PS-PS	35,051 a	U	30,965 b
		A	24,634 b			A	35,742 ab
		D	34,364 a			D	38,446 a
C	29,649 a	U	23,473 b	C-C	31,864 b	U	27,568 a
		A	30,634 ab			A	32,991 a
		D	34,540 a			D	35,032 a
PC	16,155 b	U	10,730 b	PC-PC	34,562 ab	U	31,856 a
		A	10,429 b			A	35,305 a
		D	27,307 a			D	36,525 a

Means followed by common letters are not significantly different according to Duncan's multiple-range test ($P < 0.05$). Whole-plot treatment means are compared within the same column. Subplot treatment means are compared within the same column, and within the same whole-plot treatment.

[a]Whole-plot = cropping system treatment, subplot = nematicide treatment.

[b]PS = Potato followed by sorghum-sudangrass. C = Monocropped cotton. PC = Potato double-cropped with cotton.

[c]U = Untreated. A = Aldicarb. D = 1,3-dichloropropene.

Table 8-3 Cotton treatment means for 1997 and 1998

Cropping treatment	Nematicide treatment	Yield (kg/ha)
	1997	
Monocropped cotton	Untreated	2,535 a[a]
Monocropped cotton	Aldicarb	3,247 bc
Monocropped cotton	1,3-D	3,108 c
Double-cropped cotton[b]	Untreated-Untreated[c]	595 e
Double-cropped cotton	Aldicarb-Aldicarb	3,688 ab
Double-cropped cotton	Aldicarb-1,3-D	3,859 a
	1998	
Monocropped cotton	Untreated	2,973 a
Monocropped cotton	Aldicarb	2,762 a
Monocropped cotton	1,3-D	2,832 a
Double-cropped cotton	Untreated-Untreated	801 b
Double-cropped cotton	Aldicarb-Aldicarb	2,550 a
Double-cropped cotton	Aldicarb-1,3-D	2,438 a
Rotated cotton	Untreated	2,731 a
Rotated cotton	Aldicarb	2,729 a
Rotated cotton	1,3-D	2,438 a

[a]Means followed by common letters are not significantly different according to Duncan's multiple range test ($P < 0.05$)

[b]Summer cotton double-cropped with winter potato

[c]Double-cropped treatments received two nematicide treatments each year, one on potato and one on cotton

Discussion

Rotation of cotton with potato decreased population densities of *B. longicaudatus* and *M. incognita*, the most important nematodes associated with yield losses of potato (Chapter 5, Weingartner et al., 1993, Weingartner and Shumaker, 1983) and cotton (Chapter 3) in the region. Reductions in population density of *B. longicaudatus* were greater following each year of cotton. This may be because potato followed by sorghum-sudangrass has a longer combined growing season than cotton (250 days vs. 150 days), which would provide the nematodes a longer period to reproduce. Yields of both cotton and potato were not different following rotation than when either crop was monocropped.

Double-cropping of cotton with potato resulted in high population densities of *B. longicaudatus*, a virulent pathogen of both crops. However, when a nematicide was applied to both crops, yields were comparable to either crop monocropped. Therefore, double-cropping of cotton with potato is economically viable, if *B. longicaudatus* is managed with nematicides.

In the second and third years of this study, population densities of *M. incognita* were higher following continuous potato and sorghum-sudangrass than any other cropping treatment. Both cotton (Sasser and Carter, 1985) and sorghum-sudangrass (McSorley et al., 1994a,b) are reported to be non-hosts for *M. incognita* race 1. The treatment differences may have been due to the presence of more weeds in the sorghum-sudangrass plots. Weeds were managed more intensively throughout the summer months for cotton, an economic crop, than for sorghum-sudangrass, a cover crop. Weed roots that

were galled by *M. incognita* included, redweed (*Melochia corchorifolia*), pigweed (*Amaranthus hybridus*), and common purslane (*Portulaca oleracea*).

This study shows that rotation of cotton with potato is a viable practice in northeast Florida based on population densities of plant-parasitic nematodes and crop yields. Double-cropping of potato and cotton is viable only if *B. longicaudatus* is managed with nematicides. Further work studying the effects of these cropping systems on other soilborne pathogens and production factors would be useful.

CHAPTER 9
SUMMARY

The data herein show that *Belonolaimus longicaudatus* is a major production constraint for both potato and cotton in northeastern Florida. In order for any cropping system involving either or both crops in this region to be profitable, the system must provide for management of *B. longicaudatus*. This research should facilitate the development of more efficient and profitable cropping systems for northeast Florida.

The damage function for *B. longicaudatus* on cotton was derived from field data (Chapter 3) and showed that *B. longicaudatus* is a virulent pathogen of cotton. Each nematode detected in a 130 cm^3 soil sample was associated with a yield reduction of 18.3 kg/ha of seed cotton. At high population densities of *B. longicaudatus* (> 100 nematodes/130 cm^3 of soil), yield was reduced nearly to zero. The economic threshold population density was calculated from the damage function, current nematicide application costs, and crop prices (Chapter 4). The economic threshold was 5 or less *B. longicaudatus*/130 cm^3 of soil depending on the nematicide used. *Belonolaimus longicaudatus* at low population densities ($\leq$ 10 nematodes/130 cm^3 of soil) was shown to cause about a 40% reduction in fine cotton roots. Nematicide applications for management of *B. longicaudatus* at the detection level is reasonable since the economic threshold is so low.

'DPL 5415' cotton was a good host for *B. longicaudatus* (Chapter 4). Population densities increased during the growing season under cotton, but reached a carrying capacity of approximately 140 *B. longicaudatus*/130 cm^3 of soil. Population densities of *B. longicaudatus* declined exponentially when clean fallow was maintained during the interval between cotton crops (Chapter 4). Because the population declines during fallow were greater than the increases on cotton, a general trend toward reduced population densities was predicted for successive crops of cotton. Population densities of *B. longicaudatus* were predicted to be at or below the economic threshold by the third year of continuous cotton, if a host crop was not planted between sequential cotton crops.

Belonolaimus longicaudatus also was identified as a virulent pathogen of potato in the field (Chapter 5). However, the results of pathogenicity tests were not conclusive (Chapter 6). The damage function for *B. longicaudatus* on potato was derived from field data (Chapter 5), and was used to calculate the economic threshold population density (Chapter 5). The economic threshold was 3 *B. longicaudatus*/130 cm^3 of soil for potato.

The use of sorghum-sudangrass as a cover crop was identified as a contributing factor to the maintenance of damaging population densities of *B. longicaudatus* affecting potato (Chapter 7). Mean population densities of *B. longicaudatus* following sorghum-sudangrass were 168 nematodes/130 cm^3 of soil. Under conventional northeast Florida farming practices, usually 100 days or less of fallow occurs between the sorghum-sudangrass and potato crops. From the population decline model (Chapter 4) population densities are expected to decline to near 50 *B. longicaudatus*/130 cm^3 of soil during this interval, which is well above the economic threshold of 3 *B. longicaudatus*/130 cm^3 of

and for potato. However, when a non-host cover crop (velvetbean) was substituted for sorghum-sudangrass, population densities of *B. longicaudatus* were greatly reduced (Chapter 7).

Velvetbean appeared to be a good cover crop for management of *B. longicaudatus* (Chapter 7). Initial population densities (Pi) of *B. longicaudatus* on potato were reduced following velvetbean compared with following sorghum-sudangrass ($P < 0.05$). Even though the use of velvetbean as a cover crop reduced population densities of *B. longicaudatus*, yields of the following potato crops were not increased. Velvetbean also had several other negative properties such as poor stand and susceptibility to damage by insects. Further research with velvetbean must be carried out before its use for nematode management on potato can be suggested.

Rotation of cotton with potato reduced population densities of *B. longicaudatus* and several other nematodes, compared to continuous potato followed by sorghum-sudangrass ($P < 0.05$) (Chapter 8). Yields of both potato and cotton in rotation were equivalent to those of either crop monocropped. For nematode management, rotation with cotton may be an economically viable practice for northeast Florida agriculture.

Population densities of *B. longicaudatus* were high following cotton double-cropped with potato (Chapter 8). Both crops were subject to yield reductions when nematicides were not used compared to plots treated with nematicides ($P < 0.05$). When nematicides were applied to both crops, yields were comparable to those of either crop monocropped ($P < 0.05$). Therefore, with management of *B. longicaudatus* on both

crops: double-cropping of cotton with potato may be economically viable in northeast Florida.

A total of 18 cropping system and nematicide treatment combinations were tested in the field experiment (Chapter 2). Ultimately the grower will be the one to decide the cropping systems and chemical treatments used on the farm. The grower will most likely make his decisions based on the perceived economic benefits or liabilities of each option. To aid growers in making decisions, the relative profitability of each of the 18 treatments were evaluated.

The yields of potato and cotton from all treatments were summarized for 1997 and 1998. These yields were then multiplied by the average price for each commodity received by Florida growers at the time of harvest (Anonymous, 1999) to obtain the gross crop value per acre. The average production costs of each crop, and nematicide costs of each treatment (Smith and Taylor, 1999) were then subtracted from the crop value to give the gross profit of each treatment. Profits were compared among the 18 treatments using the general linear model procedure and the means of the treatments were separated according to Duncan's multiple-range test (Ott, 1993). These results are reported in units used by the growers in the region ($/acre), rather than SI units, and are shown in Table 9-1.

Conventional farming practices for potato in northeast Florida include the use of sorghum-sudangrass as a cover crop and a nematicide applied before planting potato. With a review of the gross profits, it becomes apparent why growers in northeast Florida consistently use nematicides. The use of 1,3-dichloropropene (1,3-D) more than doubled

Table 9-1. Gross profit associated with different cropping system nematicide treatment combinations during 1997 and 1998

Treatment	Crops	Nematicides	Profit ($/acre)
1	PS-PS[a]	U[b]	1,459 d
2	PS-PS	A	2,079 cd
3	PS-PS	D	3,320 b
4	C-C	U	1,996 cd
5	C-C	A	2,338 bcd
6	C-C	D	2,207 bcd
7	PC-PC	UU	167 e
8	PC-PC	AA	3,121 bc
9	PC-PC	DA	4,956 a
10	PS-C	U	1,309 d
11	PS-C	A	1,947 cd
12	PS-C	D	2,137 bcd
13	C-PS	U	1,972 cd
14	C-PS	A	2,776 bc
15	C-PS	D	2,905 bc
16	PV-PV	U	1,908 cd
17	PV-PV	A	2,187 bcd
18	PV-PV	D	3,008 bc

Means followed by common letters are not significantly different according to Duncan's multiple-range test ($P < 0.05$)

[a] (PS) Potato followed by sorghum-sudangrass. (C) cotton. (PC) potato double-cropped with cotton. (PV) potato followed by velvetbean.

[b](U) untreated. (A) aldicarb. (D) 1,3-dichloropropene. (UU) both crops untreated. (AA) aldicarb applied to both crops. (DA) 1,3-dichloropropene applied to potato, and aldicarb applied to cotton.

gross profit in comparison to untreated potato under the conventional cropping system. Because *B. longicaudatus* was the only nematode consistently associated with yield reductions of potato ($P < 0.05$) (Chapter 5) the economic impact of managing this nematode is revealed.

Highest gross profits were obtained when potato and cotton were double-cropped, and 1,3-D was applied to potato, and aldicarb was applied to cotton. This was the only treatment with higher profit than potato with a sorghum sudangrass cover crop and application of 1,3-D. With the current crop prices and production costs, this treatment combination is the only one that produces an economic incentive to the growers to change their current production practices.

REFERENCES

Abu Gharbieh, W I, and V G Perry 1970 Host differences among Florida populations of *Belonolaimus longicaudatus* Rau Journal of Nematology 2:209-216

Agrios, G N. 1997 Plant pathology, 4th ed. San Diego, CA Academic Press

Anonymous. 1993 USGA recommendations for a method of putting green construction. <http://www usga.org/green/coned/greens/recommendations html>

Anonymous 1999 Florida agricultural facts 1998 edition. Tallahassee, FL.Florida Department of Agriculture and Consumer Services

Baird, R. E., R. F Davis, P J Alt, B G Mulinix, and G B Padgett. 1996 Frequency and geographical distribution of plant-parasitic nematodes on cotton in Georgia. Supplement to the Journal of Nematology 28 661-667.

Barker, K. R., and J P Noe. 1987 Establishing and using threshold population levels Pp. 75-81 *in* J. A. Veech, and D. W Dickson, eds Vistas on nematology Hyattsville, MD Society of Nematologists.

Bekal, S. and J O Becker 1998 Host reactions to the California population of sting nematode *Belonolaimus longicaudatus* Phytopathology 88 S7 (Abstr)

Bouyoucos, G J 1936 Directions for making mechanical analyses of soils by the hydrometer method Soil Science 42 225 229

Boyd, F T. and V. G Perry 1971 Effects of seasonal temperatures and certain cultural treatments on sting nematodes in forage grass Soil and Crop Science Society of Florida Proceedings 30 360-365

Brodie, B B 1976 Vertical distribution of three nematode species in relation to certain soil properties Journal of Nematology 8 243-247

Brodie, B B 1998 Potato Pp 567-594 in K R Barker, G A. Peterson, and G L. Windham eds Plant and nematode interactions Madison, WI American Society of Agronomy/Crop Science Society of America, Soil Science Society of America.

Campbell, K. L., J. S. Rogers, and D. R. Hensel. 1978. Watertable control for potatoes in Florida. Transactions of the American Society of Agricultural Engineering 21:701-705.

Christie, J. R., A. N. Brooks, and V. G. Perry. 1952. The sting nematode *Belonolaimus gracilis*, a parasite of major importance on strawberries, celery, and sweet corn in Florida. Phytopathology 42:173-176.

Clute, O. 1896. Cassava, the velvet bean, prickly comfrey, taro, Chinese yam, canaigre, alfalfa, flat pea, sachaline. Florida Agricultural Experiment Station Bulletin 35:329-354.

Colvin, D. L., and B. J. Brecke. 1998. Weeds in the sunshine state: Weed management in cotton-1999. University of Florida Cooperative Extension Service Document WG003. Gainesville, FL: University of Florida.

Crow, W. T., D. W. Dickson, and D. W. Weingartner. 1997. Stubby-root symptoms on cotton induced by *Belonolaimus longicaudatus*. Journal of Nematology 29:574 (Abstr.).

Crow, W. T., D. P. Weingartner, and D. W. Dickson. 1998. Reduction in root growth and yield of cotton induced by *Belonolaimus longicaudatus*. Phytopathology 88:S19 (Abstr.).

Ferris, H. 1978. Nematode economic thresholds: Derivation, requirements, and theoretical considerations. Journal of Nematology 10:341-350.

Ferris, H. 1984. Nematode damage functions: The problems of experimental and sampling error. Journal of Nematology 16:1-9.

Ferris, H., H. L. Carlson, and B. B. Westerdahl. 1994. Nematode changes under crop rotation sequences: Consequences for potato production. Agronomy Journal 36:340-348.

Fortuner, R., and M. Luc. 1987. A reappraisal of Tylenchina (Nemata). 6. The family Belonolaimidae Whitehead, 1960. Revue de Nematologie 10:183-202.

Freund, R. J., and R. C. Littell. 1981. SAS for linear models. Cary, NC: SAS Institute.

Graham, T. W., and Q. L. Holdeman. 1953. The sting nematode *Belonolaimus gracilis* Steiner: A parasite on cotton and other crops in South Carolina. Phytopathology 43:434-439.

Hochmuth, G. J., D. N. Maynard, C. S. Vavrina, W. M. Stall, T. A. Kucharek, F. A. Johnson, and T. C. Taylor. 1996. Potato production in Florida. University of Florida

Cooperative Extension Service Document CV131. Gainesville, FL: University of Florida.

Holdeman, Q. L., and T. W. Graham. 1953. The effect of different plant species on the population trends of the sting nematode. Plant Disease Reporter 37:497-500.

Holdeman, Q. L., and T. W. Graham. 1954. Effect of the sting nematode on expression of Fusarium wilt in cotton. Phytopathology 44:683-685.

Huang, X., and J. O. Becker. 1997. In vitro culture and feeding behavior of *Belonolaimus longicaudatus* on excised *Zea mays* roots. Journal of Nematology 29:411-415.

Huang, X., and J. O. Becker. 1999. Life cycle and mating behavior of *Belonolaimus longicaudatus* in Gnotobiotic culture. Journal of Nematology 31:70-74.

Jenkins, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Disease Reporter 48:692.

Johnson, A. W. 1970. Cotton (Coker 413-67). Sting nematodes (*Belonolaimus longicaudatus*). Fungicide and Nematicide Tests Reports 25:135-136.

Johnson, A. W., G. W. Burton, and W. C. Wright. 1977. Reactions of sorghum-sudangrass hybrids and pearl millet to three species of *Meloidogyne*. Journal of Nematology 9:352-353.

Johnson, A. W., N. A. Minton, T. B. Brenneman, J. W. Todd, G. A. Herzog, G. J. Gascho, S. H. Baker, and K. Bondari. 1998. Peanut-cotton-rye rotations and soil chemical treatment for managing nematodes and thrips. Journal of Nematology 30:211-225.

Johnson, F. A. 1997. Insect management in potatoes. University of Florida Cooperative Extension Service Document IG037. Gainesville, FL: University of Florida.

Kaspar, T. C., and R. P. Ewing. 1997. ROOTEDGE: Software for measuring root length from desktop scanner images. Agronomy Journal 89:932-940.

Kinloch, R. A., and R. K. Sprenkel. 1994. Plant-parasitic nematodes associated with cotton in Florida. Supplement to the Journal of Nematology 26:749-752.

Martin, S. B., J. D. Mueller, J. A. Saunders, and W. I. Jones. 1994. A survey of South Carolina cotton fields for plant parasitic nematodes. Plant Disease 78:717-719.

McSorley, R. 1998. Population dynamics. Pp. 109-133 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

McSorley, R., and D. W. Dickson. 1989a. Effects and dynamics of a nematode community on maize. Journal of Nematology 21:462-471.

McSorley, R., and D. W. Dickson. 1989b. Nematode population density increase on cover crops of rye and vetch. Nematropica 19:39-51.

McSorley, R., and D. W. Dickson. 1995. Effect of tropical crops on *Meloidogyne incognita* and other plant parasitic nematodes. Journal of Nematology 27:535-544.

McSorley, R., D. W. Dickson, and J. A. de Brito. 1994a. Host status of selected tropical rotation crops to four populations of root-knot nematodes. Nematropica 24:45-51.

McSorley, R., D. W. Dickson, J. A. de Brito, and R. C. Hochmuth. 1994b. Tropical rotation crops influence nematode densities and vegetable yields. Journal of Nematology 26:308-314.

McSorley, R., and L. W. Duncan. 1995. Economic thresholds and nematode management. Pp. 147-171 *in* J. H. Andrews, and I. Tommerup, eds. Advances in plant pathology, vol. 11. San Diego: Academic Press.

McSorley, R., and J. J. Frederick. 1991. Extraction efficiency of *Belonolaimus longicaudatus* from sandy soil. Journal of Nematology 23:511-518.

McSorley, R., and R. N. Gallaher. 1991. Nematode population changes and forage yields of six corn and sorghum cultivars. Supplement to the Journal of Nematology 23:673-677.

McSorley, R., and J. L. Parrado. 1982. Estimating relative error in nematode numbers from single soil samples composed of multiple cores. Journal of Nematology 14:522-529.

McSorley, R., and V. H. Waddill. 1982. Partitioning yield loss on yellow squash into nematode and insect components. Journal of Nematology 14:110-118.

Miller, H. K. 1902. Velvet bean. Florida Agricultural Experiment Station Bulletin 60:445-468.

Miller, L. I. 1972. The influence of soil texture on the survival of *Belonolaimus longicaudatus*. Phytopathology 62:670-671 (Abstr.)

Minton, N. A., and E. B. Minton. 1966. Effect of root knot and sting nematodes on expression of Fusarium wilt of cotton in three soils. Phytopathology 56:319-322

Mundo-Ocampo, M., J. O. Becker, and J. G. Baldwin. 1994. Occurrence of *Belonolaimus longicaudatus* on bermudagrass in the Coachella Valley. Plant Disease 78:529

Myers, R. F. 1979. The sting nematode, *Belonolaimus longicaudatus*, from New Jersey. Plant Disease Reporter 63:756-757

Myhre, D. L. 1957. Summer cover crops in potato production. Proceedings of the Florida State Horticultural Society 70:104-106

Newell, W. 1930. Velvet bean insects. Pp. 67 *in* W. Newell. University of Florida agricultural experiment station report for the fiscal year ending June 30, 1930. Gainesville, FL. University of Florida.

Nguyen, K. B., and G. C. Smart. 1975. Nematodes associated with vegetable crops in two north Florida counties. Soil and Crop Science Society of Florida Proceedings 34:187-191

Noe, J. P. 1998. Crop- and nematode management systems. Pp. 159-171 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Norton, D. C. 1959. Plant parasitic nematodes in Texas. Texas Agricultural Experiment Station Bulletin 32:1-10

Ott, R. L. 1993. An introduction to statistical methods and data analysis. Belmont, CA: Wadsworth Publishing.

Owens, J. V. 1951. The pathological effects of *Belonolaimus gracilis* on peanuts in Virginia. Phytopathology 41:29 (Abstr.)

Pan, W. L., and R. P. Bolton. 1991. Root quantification by edge discrimination using a desktop scanner. Agronomy Journal 83:1047-1052

Perez, E. E. 1997. Sampling and detection of trichodorid nematodes and tobacco rattle virus in corky-ringspot-affected tubers. PhD dissertation, University of Florida, Gainesville, FL.

Perry, V. G., and H. Rhoades. 1982. The genus *Belonolaimus*. Pp. 144-149 in R. D. Riggs, ed. Nematology in the southern region of the United States. Southern Cooperative Series Bulletin 276. Fayetteville, AR: University of Arkansas Agricultural Publications.

Rau, G. J. 1958. A new species of sting nematode. Proceedings of the Helminthological Society 25:95-98.

Rau, G. J. 1963. Three new species of *Belonolaimus* (Nematoda: Tylenchida) with additional data on *B. longicaudatus* and *B. gracilis*. Proceedings of the Helminthological Society 30:119-128.

Reddy, K. C., A. R. Soffes, G. M. Prine, and R. A. Dunn. 1986. Tropical legumes for green manure. II. Nematode populations and their effects on succeeding crop yields. Agronomy Journal 78:5-10.

Rhoades, H. L. 1976. Effect of *Indigofera hirsuta* on *Belonolaimus longicaudatus*, *Meloidogyne incognita*, and *M. javanica* and subsequent crop yields. Plant Disease Reporter 60:384-386.

Rhoades, H. L. 1983. Effects of cover crops and fallowing on populations of *Belonolaimus longicaudatus* and *Meloidogyne incognita* and subsequent crop yields. Nematropica 13:9-16.

Robbins, R. T., and K. R. Barker. 1973. Comparisons of host range and reproduction among populations of *Belonolaimus longicaudatus* from North Carolina and Georgia. Plant Disease Reporter 57:750-754.

Robbins, R. T., and K. R. Barker. 1974. The effects of soil type, particle size, temperature, and moisture on reproduction of *Belonolaimus longicaudatus*. Journal of Nematology 6:1-6.

Robbins, R. T., and H. Hirschmann. 1974. Variation among populations of *Belonolaimus longicaudatus*. Journal of Nematology 6:87-94.

Rodríguez-Kábana, R., and G. H. Canullo. 1992. Cropping systems for the management of phytonematodes. Phytoparasitica 20:211-224.

Rodríguez-Kábana, R., J. Pinochet, D. G. Robertson, and L. Wells. 1992. Crop rotations studies with velvetbean (*Mucuna deeringiana*) for the management of *Meloidogyne* spp. Supplement to the Journal of Nematology 24:662-668.

Rogers, J. S., D. R. Hensel, and K. L. Campbell. 1975. Subsurface drainage and irrigation for potatoes. Soil and Crop Science Society of Florida Proceedings 34:16-17.

Sasser, J. N., and C. C. Carter. 1985. Overview of the international *Meloidogyne* project 1975-1984. Pp. 19-24 *in* J. N. Sasser and C. C. Carter, eds. An advanced treatise on *Meloidogyne*, vol. 1. Biology and control. Raleigh, NC: North Carolina State University.

Seinhorst, J. W. 1965. The relationship between nematode density and damage to plants. Nematologica 11:137-154.

Selman, H. L. 1998. Insect pest management in cotton production. Field performance of sprinoad vs. conventional control. MS thesis, University of Florida, Gainesville, FL.

Smart, G. C., and K. B. Nguyen. 1991. Sting and awl nematodes: *Belonolaimus* spp. and *Dolichodorus* spp. Pp. 627-667 *in* W. R. Nickle, ed. Manual of agricultural nematology. New York: Marcel Dekker.

Smith, S. A., and T. G. Taylor. 1999. Production costs for selected Florida vegetables 1997-1998. Gainesville, FL: University of Florida Cooperative Extension Service. in press.

Starr, J. L. 1998. Cotton. Pp. 359-379 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Steiner, G. 1949. Plant nematodes the grower should know. Soil Science Society of Florida Proceedings 4:72-117.

Todd, T. C. 1989. Population dynamics and damage potential of *Belonolaimus* sp. on corn. Supplement to the Journal of Nematology 21:697-702.

Watkins, G. M., ed. 1981. Compendium of cotton diseases. St. Paul, MN: American Phytopathological Society.

Weaver, D. B., R. Rodríguez-Kábana, and E. L. Carden. 1993. Velvetbean in rotation with soybean for management of *Heterodera glycines* and *Meloidogyne arenaria*. Supplement to the Journal of Nematology 25:809-813.

Weingartner, D P , R. McSorley, and R. W Goth. 1993 Management strategies in potato for nematodes and soil-borne diseases in subtropical Florida. Nematropica 23 233-245

Weingartner, D P , and J R. Shumaker 1983 Nematicide options for northeast Florida potato growers Proceedings of the Florida State Horticultural Society 96 122-127

Weingartner, D P , and J R. Shumaker 1990a. Control of nematodes and soil borne diseases in Florida potatoes with aldicarb and 1,3-D Supplement to the Journal of Nematology 22 775-778

Weingartner, D P , and J R. Shumaker 1990b Effects of soil fumigants and aldicarb on corky ringspot disease and trichodorid nematodes in potato Supplement to the Journal of Nematology 22 665-671

Weingartner, D P , and J R. Shumaker 1990c Effects of soil fumigants and aldicarb on nematodes, tuber quality, and yield in potato Supplement to the Journal of Nematology 22 767-774

Weingartner, D P., J R. Shumaker, D W Dickson, and R C. Littell 1978 Nematode control on Irish potatoes in northeast Florida using a soil fumigant and a nonvolatile nematicide both alone and in combination. Journal of Nematology 10 301 (Abstr)

Weingartner, D P., J R. Shumaker, and R. C Littell 1977 Sting nematode (*Belonolaimus longicaudatus* Rau) damage to potatoes in northeast Florida. American Potato Journal 45 505-506 (Abstr).

Wright, D L., and R. K. Sprenkel 1996 Defoliating cotton. University of Florida Cooperative Extension Service Document AA207 Gainesville, FL University of Florida.

Yang, H., N T Powell and K. R. Barker 1976 Interactions of concontant species of nematodes and *Fusarium oxysporum* f sp *vasinfectum* on cotton. Journal of Nematology 8 74-80

BIOGRAPHICAL SKETCH

William T. Crow was born 3 October, 1964, in Fort Myers, Florida, where he graduated from Cypress Lake Senior High School in 1982. He began studies at the University of Hawaii at Hilo, Hawaii, in 1989, and earned the bachelor of science degree in general agriculture 1993. Next he attended Auburn University, Auburn, Alabama, where he earned the master of science degree in agronomy in 1996. His thesis title was "Effects of green manures on *Meloidogyne* (root-knot) nematodes." He began studies for the doctor of philosophy degree at the University of Florida, Gainesville, Florida, under D. W. Dickson and D. F. Weingartner in 1996. The title of his dissertation is "Host-parasite relations and management of *Belonolaimus longicaudatus* on potato and cotton."

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

D W Dickson Chair
Professor of Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

D P Weingartner Cochair
Associate Professor of Plant Pathology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

G W Simone
Professor of Plant Pathology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

R McSorley
Professor of Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

J W Noling
Associate Professor of Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Kenneth Buhr

K. L. Buhr
Assistant Professor of Agronomy

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 1999

Dean, College of Agriculture

Dean, Graduate School